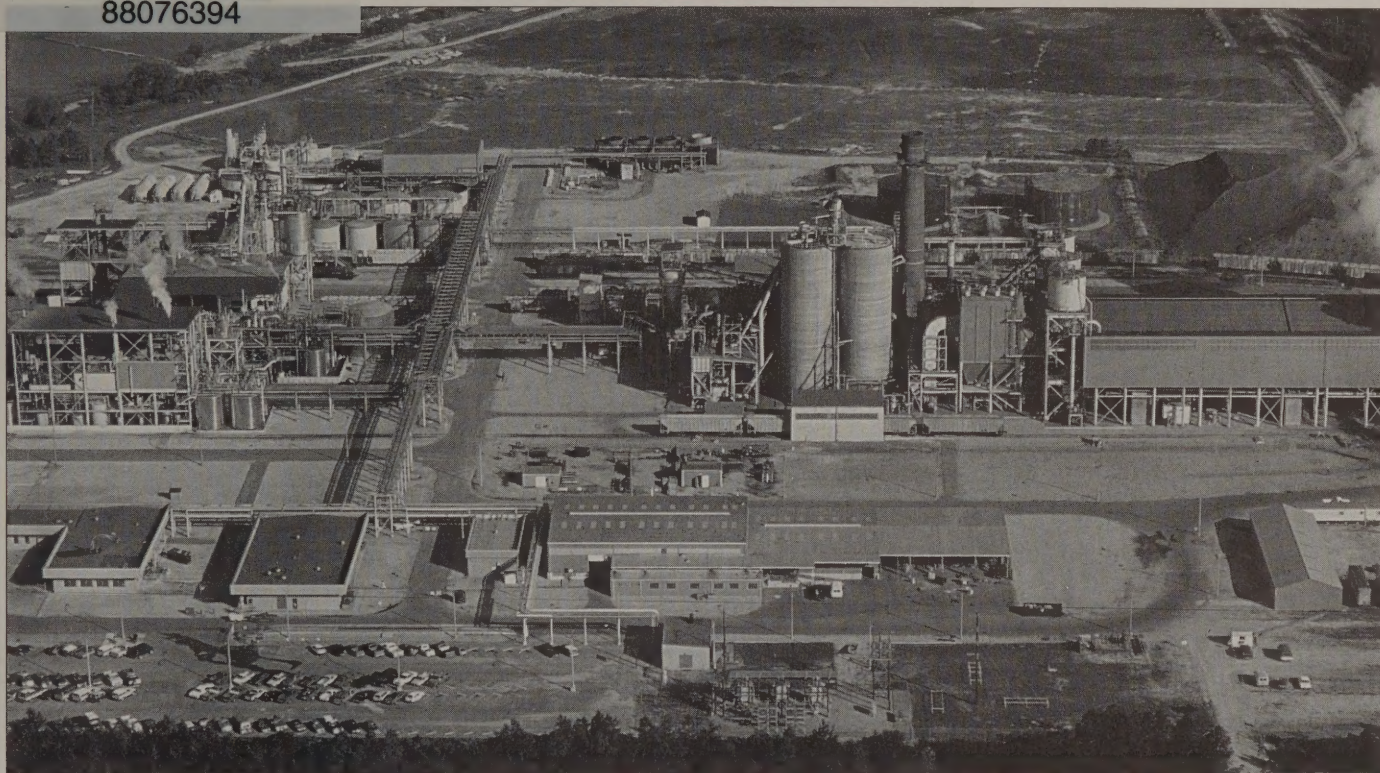


BLM LIBRARY



88076394

A N N U A L R E P O R T



CHROMIUM

By John F. Papp

1990

BLM LIBRARY

U.S. DEPARTMENT OF THE INTERIOR

BUREAU OF MINES

HD
9539
.C4
C47
1990

**BLM Library
Denver Federal Center
Bldg. 50, OC-521
P.O. Box 25047
Denver, CO 80225**

CHROMIUM



U.S.
DEPARTMENT
OF THE
INTERIOR

Manuel Lujan, Jr.
Secretary



BUREAU
OF
MINES

T S Ary
Director

November 1991

Contents

Domestic Data Coverage	1
Background	1
Definitions, Grades, and Specifications	1
Products for Trade and Industry	2
Health and Nutrition	3
Industry Structure	3
Geology-Resources	3
Technology	3
Mining	3
Beneficiation	3
Smelting	3
Recycling	5
Byproducts and Coproducts	5
Economic Factors	5
Prices	5
Costs	6
Tariffs	6
Operating Factors	7
Environmental Requirements	7
Toxicity	7
Energy Requirements	9
Transportation	9
Annual Review	9
Legislation and Government Programs	9
Strategic Considerations	11
Supply Security	11
Stockpile	11
Issues	13
Production	13
Consumption and Uses	13
Stocks	14
Prices	14
Foreign Trade	15

World Review	15
Industry Structure	16
Capacity	22
Reserves	22
Albania	24
Australia	24
Bolivia	24
Brazil	24
Canada	24
China	25
European Community	25
Finland	25
Greece	25
India	25
National	25
Chromite Ore	26
Ferrochromium	26
Indonesia	26
Iran	26
Italy	26
Japan	27
Korea, Republic of	27
Madagascar	27
New Caledonia	27
Norway	27
Oman	27
Philippines	27
Chromite Ore	27
Ferrochromium	28
South Africa, Republic of	28
Labor Relations	28
Chromite Ore	28
Ferrochromium	28
Spain	29
Sweden	29
Turkey	29
U.S.S.R.	29
United Kingdom	30
Vietnam	30
Zimbabwe	30
Current Research	30
Outlook	31

Table 6.—Salient Chromium Statistics	10
Table 7.—Historical and Projected Performance of the National Defense Stockpile Chromite Ore to Ferrochromium Conversion Program	10
Table 8.—Historical and Projected Performance of the National Defense Stockpile Low-Carbon Ferrochromium to Chromium Metal Conversion Program	11
Table 9.—U.S. Government Stockpile Goals and Yearend Inventories for Chromium in 1990	13
Table 10.—Principal U.S. Producers of Chromium Products in 1990, by Industry	14
Table 11.—Production, Shipments, and Stocks of Chromium Ferroalloys and Chromium Metal in the United States	14
Table 12.—Consumption of Chromite and Tenor of Ore Used by Primary Consumer Groups in the United States	14
Table 13.—U.S. Consumption of Chromium Ferroalloys and Metal, by End Use	15
Table 14.—U.S. Consumer Stocks of Chromite, Chromium Ferroalloys, and Metal, December 31	16
Table 15.—Price Quotations for Chromium Materials at Beginning and End of 1990	16
Table 16.—U.S. Exports and Reexports of Chromite Ore and Concentrates	17
Table 17.—U.S. Exports of Chromium Materials, by Type ...	17
Table 18.—U.S. Imports for Consumption of Chromite, by Country	18
Table 19.—U.S. Imports for Consumption of Ferrochromium, by Country	18
Table 20.—U.S. Imports of Chromium Materials, by Type ...	20
Table 21.—U.S. Import Duties for Chromium-Containing Materials in 1990	21
Table 22.—World Chromium Resources and Annual Production Capacity of Chromite Ore, Ferrochromium, Chromium Metal, and Chromium Chemicals in 1990	23
Table 23.—Chromite: World Production, by Country	30
Table 24.—Chromium Supply-Demand Relationships	32

Tables

Table 1.—Composition of Typical Chromium Ferroalloys and Chromium Metal	2
Table 2.—Principal World Chromite Producers, 1990	5
Table 3.—Principal World Ferrochromium Producers, 1990	6
Table 4.—Time-Value Relationships for Chromite Ore	7
Table 5.—Time-Value Relationships for Ferrochromium and Chromium Metal	8

COVER PHOTO:

Occidental Chemical Corp. operates the world's largest chromium chemicals plant at Castle Hayne, NC. At the plant, ground chromite ore is roasted with soda ash at temperatures above 1,100 degrees centigrade and further processed to produce sodium bichromate. Sodium bichromate is the chromium chemical from which a wide variety of other chromium chemicals are produced. (Photo is courtesy of Occidental Chemicals Co.)

Figures

Figure 1.—Chromium Material Flow	4
Figure 2.—Estimated World Chromite Ore and Ferrochromium Smelter Production Capacity, Chromium Consumption, and U.S. Chromium Stockpile in 1990	12
Figure 3.—Structure of the South African Chromium Industry in 1990	22

*For comments or further information,
please contact
The Branch of Metals
The Division of Mineral Commodities
U.S. Bureau of Mines
2401 E St., NW, MS 5208
Washington, DC 20241-0001
Telephone: (202) 634-6092
Fax: (202) 634-6016*

CHROMIUM

By John F. Papp

Dr. Papp, a physical scientist with 20 years U.S. Bureau of Mines experience, has been the commodity specialist for chromium since 1983. Domestic survey data were prepared by Lillian Wood and Robin Johnson, mineral data assistants; chromite world production data by country were prepared by Audrey D. Wilkes, international data coordinator. Cost of production data were prepared by the Minerals Availability Field Office, Division of Statistics and Information Services. (All tonnages are in metric tons unless otherwise specified.)

Chromium has a wide range of uses in metals, chemicals, and refractories. It is one of the Nation's most important strategic and critical materials. Chromium use in iron, steel, and nonferrous alloys enhances hardenability and resistance to corrosion and oxidation. The use of chromium to produce stainless steel and nonferrous alloys are two of its more important applications. Other applications are in alloy steel, plating of metals, pigments, leather processing, catalysts, surface treatments, and refractories.

Because the United States has no chromite ore reserves and a limited reserve base, domestic supply has been a concern during every national military emergency since World War I. World chromite resources, mining capacity, and ferrochromium production capacity are concentrated in the Eastern Hemisphere. The National Defense Stockpile (NDS) contains chromium in various forms, including chromite ore, chromium ferroalloys, and chromium metal in recognition of the vulnerability of long supply routes during a military emergency.

Research is conducted by the Federal Government to reduce U.S. vulnerability to potential chromium supply interruption. That research covers both domestic resource utilization and alternative materials identification. Domestic chromium resources include mineral deposits and recyclable materials. The U.S. Geological Survey and the U.S. Bureau of Mines evaluate U.S. territory for chromium mineral deposits. The U.S. Bureau of Mines also studies minerals extraction and processing and materials substitution and recycling. Alternative materials research is also conducted by the National Aeronautics and Space Administration, the National Institute of Standards and Technology, the Department of Defense, and the Department of Energy.

World chromite ore reserves are more than adequate to meet anticipated world demand.

DOMESTIC DATA COVERAGE

Domestic data coverage of the primary consuming industries—metallurgical, refractory, and chemical—are developed by the U.S. Bureau of Mines by means of the voluntary monthly "Chromite Ores and Chromium Products" survey. The companies listed in table 10 by industry accounted for 100% of the chromite consumption data by industry in the current year of table 12. All of the refractory companies and all of the chemical companies that consumed chromite in 1990 reported to the Bureau, while 75% of the metallurgical companies reported. Consumption was estimated for the remaining 25% of the metallurgical firms.

Domestic production data for chromium ferroalloys and metal are developed by the U.S. Bureau of Mines by means of two separate voluntary surveys. These two surveys are the monthly "Chromium Ores and Chromium Products" and the annual "Ferroalloys." Production by the metallurgical companies listed in table 10 represented 100% of the domestic production shown in the current year of table 11. Seventy-five percent of those companies responded to both surveys. Production for the remaining 25% was estimated.

BACKGROUND

Chromium is primarily used in the metallurgical industry as an alloying

element. That is, it is mixed with a base metal to form an alloy. Chromium confers properties on the alloy that are not achievable with the base metal alone. The most common use of chromium is with iron to make stainless steel, an iron-chromium alloy that contains chromium by definition. Chromium confers oxidation resistance to stainless steel, making it "stainless." Stainless steel, in addition to being commonly found in home and commercial kitchens, is an important engineering alloy used throughout industry in machinery and pipes. Chromium is also used in chemicals for a variety of purposes. Chromite, the mineral from which chromium is derived for use in the metallurgical and chemical industries, is used directly by the refractory industry to produce heat-, spalling-, corrosion-, and abrasion-resistant bricks for metallurgical and high-temperature industrial mineral processing applications. Chromite is not mined domestically; thus, the United States is 100% import dependent to meet domestic chromite demand. Some domestic chromium demand is met by recycling. Chromium is a critical and strategic material contained in the NDS to ensure adequate supply in the event of a national defense emergency.

Definition, Grades, and Specifications

U.S. industry sets chemical and physical specifications for chromium materials through the American Society for Testing and Materials (ASTM). Other organizations also make specifications for chromium materials. The Defense Logistics Agency (DLA), in cooperation with the Department of Commerce, maintains purchase specifications for chromium materials contained in the NDS. The Treasury Department, in cooperation with the Department of Commerce and

TABLE 1
COMPOSITION OF TYPICAL CHROMIUM FERROALLOYS AND CHROMIUM METAL
(Composition, percentage)

Material ¹	Grade	Chromium ²	Carbon ³	Silicon ³	Sulfur ³	Phosphorus ³	Nitrogen ³
Ferrochromium:							
High-carbon	A	52-58	6.0-8.0	6.0	0.040	0.030	0.050
	B	55-64	4.0-6.0	8.0-14.0	.040	.030	.050
	C	62-72	4.0-9.5	3.0	.060	.030	.050
Low-carbon	A	60-67	.025	1.0-8.0	.025	.030	.12
	B	67-75	.025	1.0	.025	.030	.12
	C	67-75	.050	1.0	.025	.030	.12
	D	67-75	.75	1.0	.025	.030	.12
Vacuum low-carbon	E	67-72	.020	2.0	.030	.030	.050
	F	67-72	.010	2.0	.030	.030	.050
	G	63-68	.050	2.0	.030	.030	5.0-6.0
Nitrogen-bearing	—	62-70	.10	1.0	.025	.030	1.0-5.0
Ferrochromium-silicon	A	34-38	.060	38-42	.030	.030	.050
	B	38-42	.050	41-45	.030	.030	.050
Chromium metal	A	99.0	.050	.15	.030	.010	.050
	B	99.4	.050	.10	.010	.010	.020

¹Chemical requirements in addition to those listed here are specified by American Society for Testing Materials (ASTM).

²Minimum, except where range of values indicating minimum and maximum appears.

³Maximum, except where range of values indicating minimum and maximum appears.

Source: 1988 Annual Book of ASTM Standards.

participants in the General Agreement on Tariffs and Trade, maintains definitions of chromium materials for the purpose of recording trade and applying tariff duties.

For the purpose of importation, chromite ore and concentrates made therefrom are classified by their chromic oxide content. Ore and concentrate is divided into three categories: containing not more than 40% chromic oxide, containing more than 40% and less than 46% chromic oxide, and containing 46% or more chromic oxide. Producers of chromite ore and concentrate typically specify chromic oxide content; chromium-to-iron ratio; and iron, silica, alumina, magnesia, and phosphorous contents. They also specify the size of the ore or concentrate. Typically, chromic oxide content ranges from 36% to 56%, with values in the 40% to 50% range being most common. Chromium-to-iron ratios typically range from about 1.5:1 to about 4.0:1, with typical values of about 1.5:1 to 3.0:1. In trade, the chromite ore is also called chromium ore, chromite, chrome ore, and chrome.

For the purpose of importation, chromium ferroalloys are classified as

ferrochromium and ferrochromiumsilicon. Ferrochromiumsilicon, also called ferrosiliconchromium and chromium silicide, is not further classified. Ferrochromium is classified by its carbon content as containing not more than 3% carbon, more than 3% but not more than 4% carbon, or more than 4% carbon. Producers of ferrochromium typically classify their material as low- or high-carbon or charge-grade ferrochromium. Charge-grade ferrochromium is also called charge chrome. Producers of chromium ferroalloys typically specify chromium, carbon, silicon, phosphorous, and sulfur contents and material size. Ferrochromiumsilicon typically contains 24% to 40% chromium, 38% to 50% silicon, and 0.05% to 0.1% carbon. Ferrochromium typically contains 50% to 75% chromium and 0.05% to 8% carbon. Low-carbon ferrochromium typically contains 55% to 75% chromium and 0.02% to 0.1% carbon. High-carbon ferrochromium typically contains 60% to 70% chromium and 6% to 8% carbon. Charge-grade ferrochromium typically contains 50% to 55% chromium and 6% to 8% carbon.

Products for Trade and Industry

Chromium is primarily used in the metallurgical industry as an alloying element. Small quantities of chromium are alloyed with (i.e., added to) a base metal to achieve certain desired properties not attainable with the base metal alone. Before its use as an alloying element, chromium was used predominantly in chemicals to make pigments or to plate metals. Chromite was used as a refractory material. As a pigment, chromium provided color to many end products and corrosion protection to ferrous metals. As a plating material, chromium provided a lustrous or a hard finish and corrosion protection to the substrate metal. As a refractory, chromite found major use in blast furnace iron production. The decline in use of this process has resulted in a corresponding decline in chromite refractory use. Environmental concern over hexavalent chromium contamination has resulted in reduced use or increased expense of chromium use in pigments and plating. Chromium is traded primarily as chromite ore or as ferrochromium. Substantial amounts of chromium chemicals, pigments, and metal are also traded.

Health and Nutrition¹

Chromium is a trace mineral required by the human body. A daily intake in the range of 50 to 200 micrograms has been recommended. Chromium is a cofactor for insulin, a hormone that participates in carbohydrate and fat metabolism. A cofactor is a material that acts with the material. The dietary chemical form of chromium is as trivalent compounds. Because humans cannot convert trivalent chromium to hexavalent chromium, the carcinogenicity of hexavalent chromium compounds bears no relevance to the nutritional role of trivalent chromium. (See Toxicity section of this report.)

Industry Structure

Stainless steel was developed in about 1900. Since then, stainless steel has grown to become the major end use of chromium. Chromium is used in stainless steel production in the form of ferrochromium, a product of smelting chromite ore with a carbonaceous material (chemical reductant) and silicious materials (flux material). The production of stainless steel evolved in association with the major steel-producing centers. The production of ferrochromium developed in conjunction with the production of stainless steel at those steel-producing locations.

In a trend toward vertical integration, chromite-producing countries have been developing ferrochromium and stainless steel production capacity. This trend has worldwide impact. Formerly, ferrochromium was produced mainly by the United States, Europe, and Japan, the major steel producers. The U.S. trend to obtain chromium in the ferroalloy form is a result of the world trend to produce ferrochromium in chromite-producing countries.

The structure of the chromium industry from a material processing perspective begins with mining of chromite ore. (See figure 1, chromium material flow.) Once mined, the ore is beneficiated. The resulting chromite ore or concentrate made therefrom may be consumed in the refractory, chemical, or metallurgical industry. Chromite ore is consumed in the refractory industry for its chromite mineral content. The chromite is typically crushed, ground, and sized. It is then mixed with magnesite to make chrome-magnesite bricks that are subsequently consumed in the steel, glass, or cement

industry. The chromite refractories are used to line steelmaking furnaces, cement kilns, or heat exchangers associated with glass production.

Chromite ore consumed in the chemical or metallurgical industry is processed to extract the chromium from the chromite mineral. Chromite ore consumed in the chemical industry is kiln roasted, and the chromium is leached out in the form of sodium bichromate. The sodium bichromate is further processed to make chromic acid and other chromium chemicals and pigments. Chromic oxide is a chemical industry product. Chromite ore consumed in the metallurgical industry is smelted to produce ferrochromium. In effect, the oxygen is removed from the iron-chromium-oxygen mineral, leaving an iron-chromium alloy, ferrochromium. Ferrochromium is produced to meet a variety of chemical and physical specifications. Several variations of the ferrochromium production process are practiced; the submerged electric arc furnace is central to each process. Ferrochromium is the source of chromium units for alloys, especially ferrous alloys. When nonferrous alloys require chromium and the iron is undesirable, chromium metal is used. Chromium metal is produced from ferrochromium by an electrolytic process or from chromic oxide by an aluminothermic process.

The major vertical structure of the chromium industry is mining-smelting-stainless steelmaking. In some instances, the ownership of mining operations, smelters, and stainless steel production facilities is integrated. In many other cases, integration is limited to mining and smelting or to smelting and stainless steelmaking. Often the ownership of operations is shared. Major mining, smelting, or stainless steel production facilities are typically privately owned by large companies or groups of companies.

Geology-Resources

The geology of many chromium deposits has been characterized.²

The data in table 22 are rated reserves and reserve base for major chromite ore-producing countries.³ The data on chromite reserves and resources are categorized according to a general U.S. Bureau of Mines-U.S. Geological Survey classification system applicable to all minerals. The definition of reserves and reserve base are published in Geological Survey Circular 831, "Principles of a Resource/

Reserve Classification for Minerals." The distribution of chromite deposits into reserves, reserve base, and resources categories is determined by the physical and chemical nature of the ore and by mining and market economies. The reserve base is the in-place demonstrated (measured plus indicated) resource from which reserves are estimated. The reserve base includes those resources that are currently economic, marginally economic, and some of those that are currently subeconomic.

Reserves are that part of the reserve base that could be economically extracted or produced at the time of determination. Reserves include only recoverable materials. Reserve values are included in reserve base values.

The term "reserves" is commonly used with a variety of definitions. Even when the definition given here is used, the quantitative value of reserves will vary owing to differing physical and economic criteria applied to a deposit by different analysts.

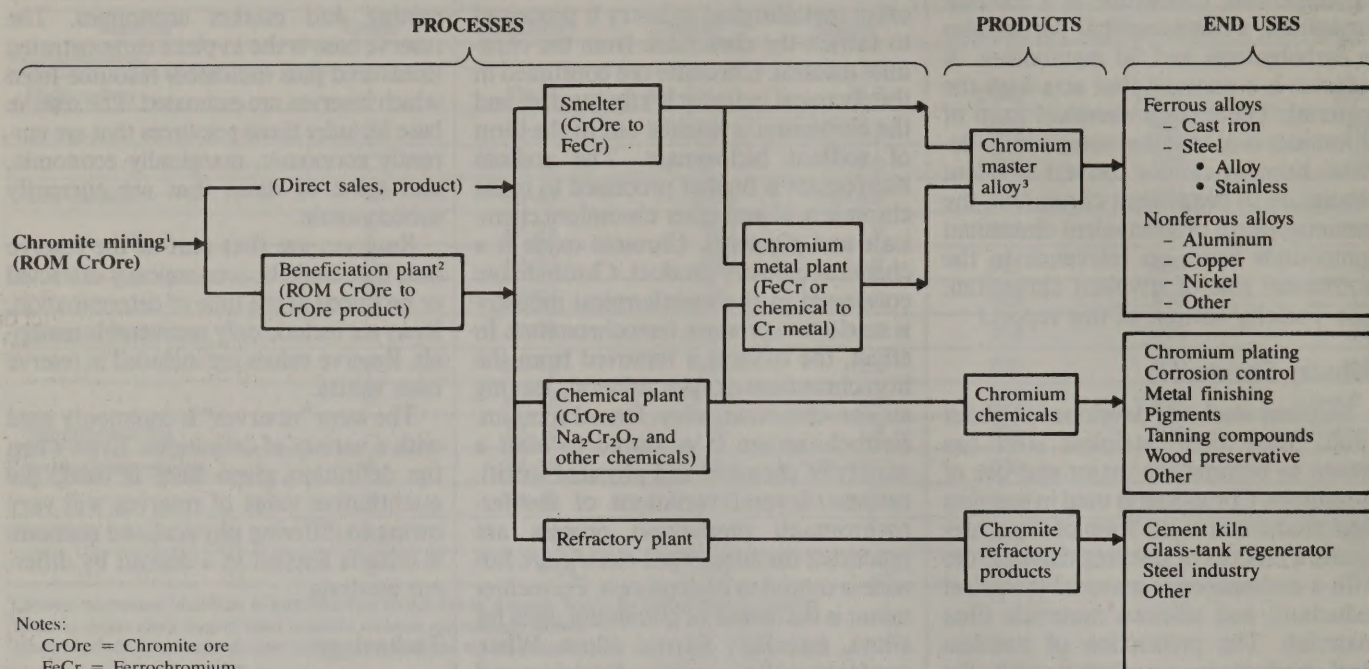
Technology

Mining.—A wide variety of mining technology is applied to the surface and subsurface mining of chromite ore. Most ore comes from large mechanized mines. However, small labor-intensive mining operations contribute to world supply.

Beneficiation.—The amount of beneficiation required and the techniques used depend on the ore source and end-use requirements. When the chromite is clean, only hand sorting of coarse material and gravity separation of fine material may be required. When the ore is lumpy and mixed with host rock, heavy-media separation may be used. When the chromite mineral occurs in fine grains intermixed with host rock, crushing may be used in conjunction with gravity separation and magnetic separation.

Smelting.—The smelting of chromite ore to produce ferrochromium requires electric arc furnace technology. Early electric furnaces having power ratings in the kilovolt-ampere range have developed into modern furnaces having power ratings of about 50 megavolt-amperes. Closed and partially closed electric arc furnaces replaced open furnaces in the 1970's to improve pollution control, efficient furnace operation, and safety. Industry is developing new production

FIGURE 1
CHROMIUM MATERIAL FLOW



Notes:

CrOre = Chromite ore
FeCr = Ferrochromium
Na₂Cr₂O₇ = Sodium bichromate
ROM = Run-of-Mine

¹Mining includes screening and hand sorting.

²Beneficiation includes crushing, grinding, and separation techniques, including gravimetric, heavy media, and magnetic.

³Master alloy is an alloy used as a feedstock to produce other alloys.

technologies using high-temperature plasmas or using alternatives to electrical power supply. The new production technologies are expected to be more cost competitive than traditional production technology.

Technological change in stainless steel production permitted the replacement of expensive high-chromium, low-carbon ferrochromium by less expensive

low-chromium, high-carbon ferrochromium. This change permitted the use of low chromium-to-iron ratio ore for smelting to ferrochromium, which is subsequently alloyed to produce stainless steel. The Republic of South Africa is the most abundant and low-cost source of such ore. Unfortunately, this ore is friable (breaks easily into small pieces), and the finer fractions of such ore are blown out

of a furnace before it can be smelted. Agglomeration technology has been developed to permit the use of fine chromite ore in the electric arc furnace. Both briquetting and pelletizing are practiced. Efficient production technology uses prereduced and preheated pelletized furnace feed. Advanced smelting technologies have been designed to use fine ore.

TABLE 2
PRINCIPAL WORLD CHROMITE PRODUCERS, 1990

Country ¹	Company
Albania	Government owned.
Brazil	Bayer AG (Federal Republic of Germany)
	Coitezeiro Mineração S.A. (COMISA).
	Cia. de Ferro-Ligas de Bahia S.A. (FERBASA).
	Cia. de Mineração Serra de Jacobina S.A. (SERJANA).
	Mineração Vale do Jacurici S.A.
	Magnesita S.A.
Finland	Outokumpu Oy (Government owned).
India	Ferro Alloys Corp. Ltd.
	Misrilal Mines Pvt. Ltd.
	Mysore Mineral Ltd.
	Orissa Mining Corp. Ltd. (Government owned).
	Tata Iron and Steel Co. (TISCO).
Philippines	Acoje Mining Co. Inc.
	Benguet Corp.
	Philchrome Mining Corp.
South Africa, Republic of	African Mining and Trust Co. Ltd.
	Zeerust Chrome Mine Ltd.
	Rustenburg Minerals Development Co. (Pty.) Ltd.
	Chrome Chemicals SA (Pty.) Ltd.
	Chromecorp Technology (Pty.) Ltd.
	Chroombronne (Pty.) Ltd.
	Lavino South Africa (Pty.) Ltd.
	Grootboom Chrome Mine.
	Lebowa Development Corp. Ltd.
	Dilokong Chrome Mine.
	National Manganese Mines (Pty.) Ltd.
	Buffels Chrome Mine.
	Rand Mines Ltd.
	Millsell Chrome Mines (Pty.) Ltd.
	Henry Gould (Pty.) Ltd.
	Samancor Ltd.
	Bathako Mining Ltd.
	Ruighoek Chrome Mine.
	Grasvally Chrome Mine.
	Jagdlust Mine.
	Montrose Mine.
	Mooiooi Mine.
	Waterkloof Chrome Mines (Pty.) Ltd.
	Vansa Vanadium S.A. Ltd.
	Winterveld Chrome Mines Ltd.
	Vereeninging Refractories Ltd.
	Marico Chrome Corp. (Pty.) Ltd.
Turkey	Etibank (Government owned).
	Bursa Toros Kromlari AS.
	Egemetal Madencilik AS.
	Sitki Kocman Mines.

See footnotes at end of table.

Recycling.—Recycling is the only domestic supply source of chromium. Stainless steel and superalloys are recycled, primarily for their nickel and chromium contents. As much as 50% of electric furnace stainless steel production can result from recycled prompt and purchased stainless steel scrap. Advanced stainless steel production technology like continuous casting reduces prompt scrap generation and permits a higher product yield per unit of raw material feed.

Byproducts and Coproducts

Chromium is mined as a primary product. Chromium is not a byproduct or coproduct of the mining of any mineral, nor are there byproducts or coproducts associated with chromium mining. Chromium has the potential of becoming a byproduct of platinum mining in the Republic of South Africa or of lateritic nickel mining. Platinum and chromite are both present in the UG2 seam of the Bushveld Complex in the Republic of South Africa. At present, most platinum mining is from the Merensky Reef. However, as platinum mining from the UG2 seam continues and as new mining operations that exploit the UG2 seam are developed, chromium-containing tailings will continue to grow. The feasibility of utilizing these resources has been demonstrated, and new ferrochromium production facilities under development by Middelburg Steel and Alloys are designed to permit the use of these resources. It appears to be only a matter of time before economic conditions favor the use of those tailings, thereby making chromium a byproduct of some platinum operations.

Economic Factors

Prices.—Inadequate supplies of ferrochromium in the late 1980's resulted from strong demand for stainless steel in all three major producing regions: the United States, Japan, and Europe. This inadequate supply resulted in increasing ferrochromium prices until mid-1989, when supply exceeded demand and prices began to decline. In 1989 and 1990, new ferrochromium plants and plant expansions were under construction or being completed. Reduced stainless steel production permitted ferrochromium producers, traders, and consumers to rebuild stocks after about 3 years of generally increasing production. Reduced demand for ferrochromium, resulting

TABLE 2—Continued

PRINCIPAL WORLD CHROMITE PRODUCERS, 1990

Country ¹	Company
Turkey—Continued	Turk Maadin Sirketi AS.
	Hayri Ogelman Madencilik AS.
U.S.S.R.	Government owned.
Zimbabwe	Zimbabwe Alloys Ltd. (Zimalloys).
	Zimbabwe Mining and Smelting Co. (Pvt.) Ltd. (Zimasco).

¹Other chromite-producing countries included Bulgaria, China, Cuba, Greece, Indonesia, Iran, Japan, Madagascar, New Caledonia, Pakistan, Sudan, Thailand, Yugoslavia, and Vietnam.

TABLE 3

PRINCIPAL WORLD FERROCHROMIUM PRODUCERS, 1990

Country ¹	Company
Brazil	Cia. de Ferro-Ligas da Bahia S.A. (FERBASA).
China	Government owned.
Finland	Outokumpu Oy (Government owned).
France	Chromeurope S.A.
Germany, Federal Republic of	Gesellschaft für Elektrometallurgie mbH (GfE)
	Elektrowerk Weisweiler GmbH.
Greece	Hellenic Ferroalloys S.A.
India	Ferro Alloys Corp. Ltd. (Facor)
	Indian Metals & Ferroalloys Ltd. (IMFA).
	Indian Charge Chrome Ltd.
	Industrial Development Corp.
	OMC Alloys Ltd. (State owned)
	Visvesvaraya Iron & Steel Ltd. (State owned)
Italy	Darfo Srl.
	Acciaierie e Ferriere Lombarde Falck SpA.
	Ferroleghes SpA.
	Fucinati SpA.
Japan	Japan Metals and Chemicals Co. Ltd.
	Nippon Denko Co. Ltd.
	NKK Corp.
	Pacific Metals Co. Ltd.
	Showa Denko K.K.
Norway	Elkem Rana.
Philippines	Ferro Chemicals Inc.
	Ferrochrome Philippines Inc.
	Integrated Chrome Corp.
South Africa, Republic of	Anglovaal Ltd.
	Feralloys Ltd.
	Chromecorp Technology (Pty.) Ltd.
	Johannesburg Consolidated Investment Co. Ltd.
	Consolidated Metallurgical Industries Inc.
	Middelburg Steel and Alloys Holdings (Pty.) Ltd.
	Alloys Division Middelburg.

See footnotes at end of table.

from decreased stainless steel production, and increased supply of ferrochromium, resulting from producer expansions and new plant construction, have resulted in declining ferrochromium prices through 1990.

The historical value of chromite ore by grade, ferrochromium by grade, and chromium metal imported to the United States is shown in tables 4 and 5. These values show that as chromite ore is processed to ferrochromium and to chromium metal, the added value is quite large. On a per unit of contained chromium basis, the value of ferrochromium is about 7 times that of chromite ore; the value of chromium metal is about 30 times that of chromite ore. Variations of the value of ore are shown to follow those of ferrochromium, indicating values of chromite ore change in response to demand with ferrochromium value first to reflect demand changes.⁴ Ferrochromium values show greater variation than those of chromite ore. The unit value of chromium materials has increased by 10% to 15% per year in actual value since 1963.

Costs.⁵—Operating and transportation are the two major components of chromite ore cost in the market place. Operating cost includes mining (the production of run-of-mine ore) and beneficiation (the production of marketable chromite ore or concentrate from the run-of-mine ore). Mining cost is typically in the range of 70% to 90% of operating cost but exceeds 90% in some cases. Labor cost is the major component of mining and of beneficiation cost. Labor cost is typically in the range of 20% to 70% of mining cost and from 25% to 90% of beneficiation cost, but can be higher.

Electrical energy, raw materials, and labor are the major components of smelting (i.e., production of ferrochromium from chromite ore) cost. (Note that smelting cost excludes the cost of chromite ore feed material.) Electrical energy cost is in the range of 20% to 55% of smelting cost; raw materials (excluding chromite ore), 15% to 35%; and labor, 10% to 30%.

Tariffs.—Import tariffs are typically imposed to protect domestic industry. Where there is no domestic industry, such as chromite ore production in the United States, there is no tariff. (See Foreign Trade section of this report for U.S. tariff

TABLE 3—Continued

PRINCIPAL WORLD FERROCHROMIUM PRODUCERS, 1990

Country ¹	Company
South Africa, Republic of—Continued	Alloys Division Krugersdorp.
	Samancor Ltd.
	Bathako Ferrochrome Ltd.
	Ferrometals Ltd.
	Tubatse Ferrochrome (Pty.) Ltd.
Sweden	Vargön Alloy AB.
Turkey	Etibank (Government owned).
U.S.S.R.	Government owned.
United States	Elkem Metals Co.
	Macalloy Corp.
	SKW Alloys Inc.
Yugoslavia	Tvornica Karbida i Ferolegura Dalmacija.
	Tovarna Dušika Ruše.
Zimbabwe	Zimbabwe Alloys Ltd. (Zimalloys).
	Zimbabwe Mining and Smelting Co. (Pvt.) Ltd. (Zimasco).

¹Other ferrochromium-producing countries included Albania, Chile, Czechoslovakia, Poland, Mexico, Romania, Spain, and Taiwan.

duties on chromium materials.) In some cases, such as ferrochromium imports to the European Community, import tariffs are used along with import quotas. That is, a duty-free quota is allocated to member countries. The quotas may be revised as necessary to meet the needs of domestic consumers and producers. Only in a few cases, such as ferrochromium exports from China and certain grades of chromite ore exports from India, are export duties applied.

Operating Factors

Environmental Requirements.—Chromium releases into the environment are regulated by the Environmental Protection Agency (EPA). Workplace exposure is regulated by the Occupational Safety and Health Administration.

Toxicity.⁶—The toxic effect of an element depends on its chemical form and concentration, and on the conditions and

TABLE 4
TIME-VALUE¹ RELATIONSHIPS FOR CHROMITE ORE

(Average annual value, dollars per metric ton of contained chromium)

Year	Not more than 40% chromic oxide		More than 40% but less than 46% chromic oxide		46% or more chromic oxide		Total, all grades	
	Actual	1982	Actual	1982	Actual	1982	Actual	1982
1963	86	28	40	13	63	20	54	17
1964	84	28	44	14	59	19	57	19
1965	88	30	48	16	59	20	59	20
1966	82	29	45	16	62	22	58	20
1967	87	31	48	17	66	24	62	22
1968	81	31	45	17	60	23	59	22
1969	75	30	51	20	66	26	64	25
1970	85	36	53	22	90	38	79	33
1971	98	43	58	26	98	43	87	39
1972	99	46	62	29	94	44	89	41
1973	104	52	55	27	93	46	82	41
1974	109	59	67	36	104	56	96	52
1975	178	106	101	60	209	124	175	104
1976	222	140	146	92	262	165	212	134
1977	235	158	166	112	254	171	206	138
1978	230	166	177	128	185	134	200	144
1979	240	189	187	147	232	182	215	169
1980	288	247	195	167	189	162	222	190
1981	266	250	192	181	184	173	219	206
1982	293	293	201	201	213	213	229	229

See footnotes at end of table.

TABLE 4—Continued
TIME-VALUE¹ RELATIONSHIPS FOR CHROMITE ORE
(Average annual value, dollars per metric ton of contained chromium)

Year	Not more than 40% chromic oxide		More than 40% but less than 46% chromic oxide		46% or more chromic oxide		Total, all grades	
	Actual	1982	Actual	1982	Actual	1982	Actual	1982
1983	359	373	172	179	166	172	194	202
1984	403	434	141	151	156	168	186	200
1985	261	290	160	178	160	177	184	205
1986	218	248	145	164	146	166	163	186
1987	185	217	160	188	155	182	168	197
1988	241	292	269	¹ 326	187	227	229	278
1989	292	¹ 369	290	¹ 366	247	¹ 313	271	¹ 342
1990	313	^P 411	228	^P 300	237	^P 312	242	^P 318

^PPreliminary. ¹Revised.

¹Customs value per ton of chromium contained in imported material.

NOTE.—1982 value is actual value multiplied by gross national product (GNP) ratio. GNP ratio is annual GNP divided by 1982 GNP. GNP ratio calculated as the ratio of GNP index reported in Economic Report of the President, U.S. Government, February 1990, available from Superintendent of Documents, U.S. Government Printing Office.

TABLE 5
TIME-VALUE¹ RELATIONSHIPS FOR FERROCHROMIUM AND CHROMIUM METAL
(Average annual value)

Year	Ferrochromium (dollars per metric ton of contained chromium)						Chromium metal (dollars per metric ton gross weight)	
	Low-carbon ²		High-carbon ³		Total, all grades		Actual	1982
	Actual	1982	Actual	1982	Actual	1982		
1963	397	129	290	94	376	122	1,677	543
1964	380	125	304	100	360	119	1,670	549
1965	408	138	268	90	395	133	1,661	561
1966	410	143	232	81	367	129	NA	NA
1967	417	150	264	95	394	142	NA	NA
1968	399	151	261	98	382	144	1,656	624
1969	426	169	236	94	370	147	1,800	717
1970	453	190	272	114	401	168	NA	NA
1971	585	260	342	152	464	206	2,003	889
1972	556	258	282	131	422	196	2,206	1,026
1973	617	305	289	143	392	194	2,491	1,233
1974	797	431	512	277	600	324	3,030	1,636
1975	1,534	910	942	558	1,061	629	4,486	2,660
1976	1,406	887	719	454	916	578	4,350	2,745
1977	1,385	932	702	472	826	556	4,938	3,324
1978	1,405	1,014	640	462	686	496	NA	NA
1979	1,737	1,366	853	671	945	743	NA	NA
1980	1,826	1,565	890	762	972	833	7,682	6,584
1981	1,609	1,513	870	817	952	895	7,662	7,203
1982	1,551	1,551	887	887	1,008	1,008	6,018	6,018
1983	1,437	1,493	683	710	737	766	4,491	4,667

See footnotes at end of table.

TABLE 5—Continued

TIME-VALUE¹ RELATIONSHIPS FOR FERROCHROMIUM AND CHROMIUM METAL

(Average annual value)

Year	Ferrochromium (dollars per metric ton of contained chromium)						Chromium metal (dollars per metric ton gross weight)	
	Low-carbon ²		High-carbon ³		Total, all grades		Actual	1982
	Actual	1982	Actual	1982	Actual	1982		
1984	1,496	1,612	782	843	833	897	5,674	6,111
1985	1,571	1,742	847	939	914	1,013	5,468	6,064
1986	1,409	1,604	779	886	851	968	5,320	6,055
1987	1,544	1,812	783	919	893	1,049	6,098	7,159
1988	1,988	2,412	1,317	1,598	1,403	1,702	7,231	8,772
1989	¹ 1,908	¹ 2,410	1,524	¹ 1,924	1,609	¹ 2,032	¹ 6,598	¹ 8,333
1990	1,619	^P 2,129	1,883	^P 1,161	1,017	^P 1,337	6,459	^P 8,494

^PPreliminary. ¹Revised. NA Not available.¹Customs value per ton of chromium contained in imported material.²Carbon not more than 4%.³More than 4% carbon.

NOTE.—1982 value is actual value multiplied by gross national product (GNP) ratio. GNP ratio is annual GNP divided by 1982 GNP. GNP ratio calculated as the ratio of GNP index reported in Economic Report of the President, U.S. Government, February 1990, available from Superintendent of Documents, U.S. Government Printing Office.

duration of exposure. At about 200 parts per million, chromium is the sixth most common element in the Earth's crust; at 1 to 2.5 parts per billion, the fifteenth most common element in seawater. Chromium generally forms chemical compounds in which chromium has either the hexavalent or trivalent oxidation state. Hexavalent chromium compounds are generally recognized as toxic. Chronic occupational exposure to hexavalent chromium has been associated with an increased incidence of bronchial cancer. The toxic status of trivalent chromium compounds is not clear. However, trivalent chromium compounds are less toxic than hexavalent chromium compounds. Chemical compounds containing chromium in lower valence states are generally recognized as benign. (See Health and Nutrition section of this report.)

Energy Requirements.—Ferrochromium production is an energy-intensive process, requiring about 3,800 kilowatt-hours per metric ton of product. Currently available technology can reduce the electrical energy requirement to about 2,000 kilowatt-hours per ton by thermal energy recovery and recycling. Traditional technology uses electricity to supply the energy required to smelt chromite ore. Advanced production technology permits the use of liquid or gas fuel to substitute

for part of the energy required. Alternative production technology is being developed that would permit nonelectrical energy sources to supply a significant fraction of the energy required to smelt chromite ore.

Transportation.—Chromite ore is typically transported by trackless truck or conveyor belt from the mine face to storage or processing facilities on the mine site. From there, it is transported by truck from the mine site to the local railhead. It is then transported by rail to ports or to smelters. Smelters that do not have associated loading and unloading facilities for ships transport their product by rail to ports. Following transport by ship to consumer countries, chromium materials are typically barged or hauled by truck to end users who have no loading and unloading facilities for ships.

ANNUAL REVIEW

In 1990, chromium apparent consumption was 447,000 metric tons of contained chromium. The reported consumption of chromite by the chemical and metallurgical industry and by the refractory industry decreased. Metallurgical industry chromite consumption includes material

consumed as part of the NDS program to convert chromite to ferrochromium. Imports of chromite decreased, while imports of chromium ferroalloys increased compared with those of 1989.

U.S. supply consisted of recycled and imported chromium materials. The United States recycled about 561,000 tons, gross weight, of stainless steel scrap and imported about 742,000 tons of chromite ore, ferroalloys, chemicals, and pigments valued at about \$338 million. The United States exported about 25,000 tons of chromium materials valued at about \$36 million.

Legislation and Government Programs

In accordance with the President's November 1982 directive and Public Law 99-591, the DLA continued to upgrade NDS chromite ore to high-carbon ferrochromium. The Agency reported conversion of chromite ore to ferrochromium on a calendar year contract basis. DLA signed a contract with Macalloy Corp., Charleston, SC, in 1990 to upgrade NDS chromite ore. The contract period covers the years 1990 through 1994, the last 2 years of which are optional for DLA.

As part of its plan to modernize the NDS, DLA contracted with Elkem Metals Co., Marietta, OH, to upgrade

TABLE 6
SALIENT CHROMIUM STATISTICS

(Thousand metric tons, gross weight)

	1986	1987	1988	1989	1990
CHROMITE					
United States:					
Exports	84	1	4	40	6
Reexports	1	5	1	2	4
Imports for consumption	443	490	615	525	306
Consumption	388	506	551	561	402
Stocks, Dec. 31: Consumer	285	332	390	392	355
World production	^a 11,797	^a 11,637	^a 12,593	^a 13,542	^a 12,846
CHROMIUM FERROALLOYS¹					
United States:					
Production ²	96	107	120	147	109
Exports	5	5	8	9	9
Reexports	1	2	2	2	2
Imports for consumption	361	303	431	351	420
Consumption	331	396	413	^a 354	382
Stocks, Dec. 31: Consumer	29	23	30	^a 19	17
World production ³	^a 2,964	^a 3,148	^a 3,273	^a 3,288	NA

^aEstimated. ¹Revised. NA Not available.

¹High-, medium-, and low-carbon ferrochromium plus ferrochromium-silicon.

²Includes chromium metal, exothermic chromium additives, and other miscellaneous alloys.

³As reported in the 1989 Ferroalloys annual report.

TABLE 7
HISTORICAL AND PROJECTED PERFORMANCE OF THE
NATIONAL DEFENSE STOCKPILE CHROMITE ORE TO
FERROCHROMIUM CONVERSION PROGRAM

Contract year	Ore converted (metric tons)	High-carbon ferrochromium produced (metric tons)		Cost (millions)
		Gross	Content	
HISTORICAL PERFORMANCE				
1984	113,968	45,590	30,180	\$22.3
1985	124,298	44,872	29,630	22.5
1986	85,301	31,944	20,898	17.6
1987	125,739	52,414	40,058	28.8
1988	111,105	41,511	26,727	26.7
1989	120,651	46,940	30,392	31.5
1990	113,453	42,881	28,082	30.9
PROJECTED PERFORMANCE ^c				
1991	114,615	46,496	NA	30.6
1992	103,977	46,707	NA	32.7
1993	112,238	51,424	NA	34.2

^aEstimated. NA Not available.

Source: Defense Logistics Agency.

NDS nonspecification-grade low-carbon ferrochromium into electrolytic (vacuum melting-grade) chromium metal. In 1989, Elkem was awarded a \$7.2 million contract to convert 2,129 metric tons of low-carbon ferrochromium to about 1,043 metric tons of chromium metal during a 1-year period starting in December 1989. That contract was completed in December 1990. In 1990, DLA awarded a contract to Elkem to convert about 1,090 tons of low-carbon ferrochromium to about 779 tons of chromium metal at a cost of about \$7.0 million, with completion scheduled for 1991. A second year of this contract is optional for DLA.

DLA continued a program to evaluate plasma smelting technology. The program was being carried out by South Carolina Research Authority (SCRA), along with Macalloy Corp., Massachusetts Institute of Technology, Clemson University, and Arthur D. Little Inc. In 1990, a pilot-scale (2,000 kilowatt) furnace, capable of producing about 500 kilograms of ferrochromium per hour, was built at Macalloy's smelting facility in Charleston, SC. After successful test firings of the furnace, several production campaigns were run by SCRA and Macalloy. The group is expected to now plan, develop, and construct a larger prototype furnace.

DLA revised the goal for refractory-grade chromite ore in the NDS to 630,000 metric tons as authorized by Congress in the National Defense Authorization Act for Fiscal Years 1990 and 1991. This revision represents a goal reduction of 18%. The stockpile inventory remains unchanged at a level equivalent to about 56% of the revised stockpile goal.⁷

EPA completed its rulemaking on chromium containing treated residues from roasting and/or leaching of chrome ore with the publication of its final rule.⁸ EPA recommended treated residues from roasting and/or leaching of chrome ores to be regulated under subtitle D of the Resource Conservation and Recovery Act. EPA found no significant danger associated with treated residue from roasting and/or leaching of chrome ore based on waste characteristics, management practices, and damage case investigations.⁹

Chromite refractory use could be significantly impacted by EPA regulation of waste containing chromium. EPA has determined that chromium-containing

TABLE 8

HISTORICAL AND PROJECTED PERFORMANCE OF THE NATIONAL DEFENSE STOCKPILE LOW-CARBON FERROCHROMIUM TO CHROMIUM METAL CONVERSION PROGRAM

Time period	Low-carbon ferrochromium ¹ (metric tons)	Chromium metal (metric tons)	Cost (millions)
HISTORICAL PERFORMANCE			
1989-90	2,129	1,043	\$7.3
PROJECTED PERFORMANCE^a			
1990-91	1,090	779	7.0

^aEstimated.¹Nonspecification grade.

Source: Defense Logistics Agency.

wastes exhibit toxicity. EPA has, therefore, established a policy that, if the extract from a representative waste sample contains chromium at a concentration greater than or equal to 5.0 milligrams per liter (total chromium), it is hazardous. EPA has promulgated a treatment standard for chromium-containing refractory brick wastes based on chemical stabilization. (Stabilization is a process that keeps a compound, mixture, or solution from changing its form or chemical nature.) EPA has also determined that some chromium-containing refractory brick wastes can be recycled as feedstock in the manufacture of refractory bricks or metal alloys. EPA recognized that there is insufficient capacity to process inorganic solid debris (i.e., treatable material that is greater than 9.5 millimeters in size and requires cutting or crushing and grinding in mechanical sizing equipment) prior to chemical stabilization. As such a material, chromite-containing refractory bricks were granted a 2-year capacity variance (i.e., a variance until May 1992).¹⁰

Congress enacted the Clean Air Act Amendments Law of 1990 (Public Law 101-549), completely revising the Air Toxics Program. Congress identified 189 hazardous air pollutants to be regulated. Chromium compounds—defined as any unique chemical substances that contain chromium as part of their infrastructure—were included among those hazardous air pollutants. Under the revised Air Toxics Program, Congress instructed EPA to regulate hazardous air pollutants by regulating the source of those pollutants. Congress required EPA to identify pollution sources by November 1991, then to set emission standards for those

sources. The Act included a provision for EPA to review petitions to delete specific pollution sources or chemicals identified as hazardous air pollutants from those identified by Congress or EPA.¹¹

Motion pictures and videotape programs distributed by the U.S. Bureau of Mines are designed to inform viewers of the importance of minerals in our society and of the need for conservation of these finite resources. The Bureau made "Chromium," a new video recording, available to the public.¹²

Strategic Considerations

U.S. strategic minerals policy and practice has recently been reviewed and analyzed. The United States is import dependent for its chromium needs. This dependence results from our economic system, a system that requires most economically exploitable resources to be used first. The economic system that causes dependence also benefits all consumers by providing low-cost materials. Dependence was found to result in supply vulnerability due to long supply routes between chromium sources and the United States. U.S. policy is to reduce the risk of supply disruption in the event of a national emergency by maintaining a stockpile. Other policy alternatives not currently practiced include resource sharing, diversifying supply sources, and technological changes.¹³

Supply Security.—There is no production of chromite ore in the United States; primary consumption of chromium by U.S. industry is by companies that use chromite ore to produce ferrochromium, chromium chemicals, and chromite

refractories and by chromium metal producers that use ferrochromium or chromium chemicals (i.e., chromic oxide). Chromite ore reserves are abundant, ensuring adequate long-term supply. However, supply sources are few and remote from the United States, making supply vulnerable to disruption. The problem for the United States is one of national security. Ferrochromium is essential to stainless and some alloy steel production, which are in turn essential to both the domestic economy and to the production of military hardware.

U.S. supply of chromium (contained in chromite ore and chromium ferroalloys and metal) was predominantly from the Republic of South Africa (50%), Turkey (11%), Zimbabwe (11%), and Yugoslavia (9%). Imports from the Republic of South Africa are currently restricted by the Comprehensive Anti-Apartheid Act (Public Law 99-440). In 1987 and again in 1989, the Department of State determined chromium (including ferrochromium) to be a critical and strategic material unavailable from reliable alternative sources, making it possible to import chromite ore and ferrochromium from the Republic of South Africa. Figure 2 summarizes world chromite ore and ferrochromium production capacity and chromium consumption, comparing centrally planned economy countries with market economy countries. The figure also shows NDS inventory.

Stockpile.—The NDS contains the following chromium materials: chromite ore, chromium ferroalloys, and chromium metal. The purpose of the NDS is to supply military, essential civilian, and basic industrial needs of the United States during a national defense emergency, and by law the stockpile cannot be used for economic or budgetary purposes. In addition to private and Government stocks, there exists a large unreported inventory of chromium contained in products, trader stocks, and scrap. The amount of these stocks varies with demand and price of the material. Under severe price pressures resulting from primary chromium shortages, recycling of consumer materials could add to the supply.

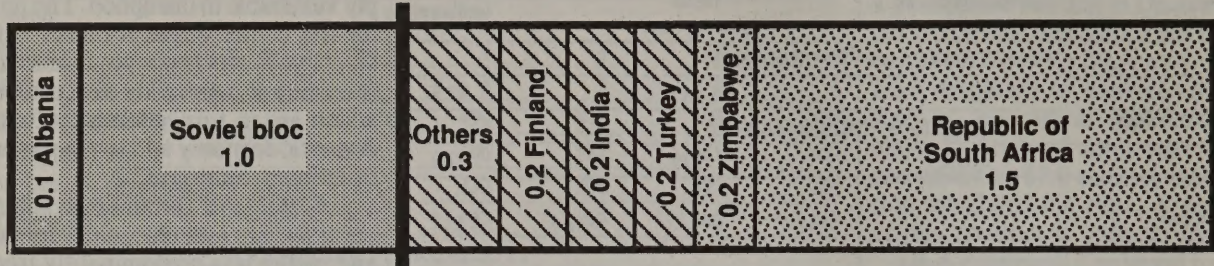
Chromite ore must be converted to ferrochromium before it can be used to make steel. Prompt response during a national defense emergency requires that conversion be carried out by domestic industry. However, domestic ferrochromium production capacity is not adequate

FIGURE 2

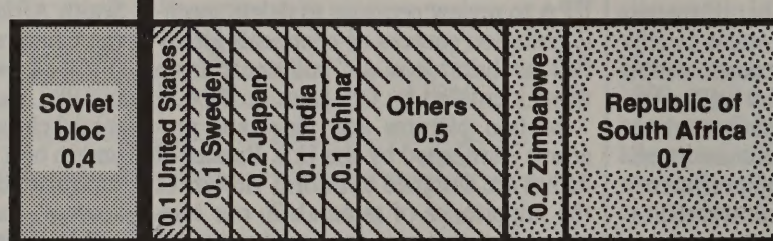
ESTIMATED WORLD CHROMITE ORE AND FERROCHROMIUM SMELTER PRODUCTION CAPACITY, CHROMIUM CONSUMPTION, AND U.S. CHROMIUM STOCKPILE IN 1990

(Million metric tons of chromium content)

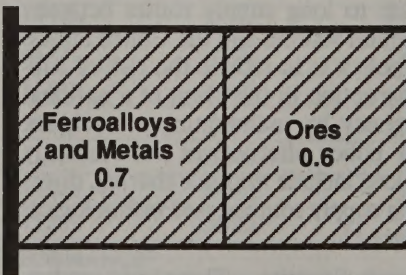
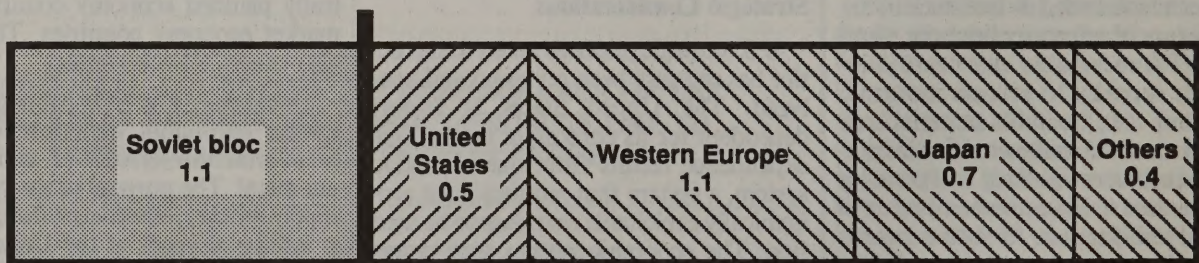
Mine capacity (chemical, metallurgical, and refractory ores)



Smelter capacity (metallurgical ores)



Consumption (all forms)



**TOTAL
U.S.
STOCKPILE**

TABLE 9

U.S. GOVERNMENT STOCKPILE GOALS AND YEAREND INVENTORIES FOR CHROMIUM IN 1990

(Thousand metric tons, gross weight)

Material	Stockpile goals	Physical inventory		Total
		Stockpile-grade	Nonstock-pile-grade	
Chromite, metallurgical	2,903	1,287	252	1,539
Chromite, chemical	612	220	—	220
Chromite, refractory	630	355	—	355
High-carbon ferrochromium	168	628	1	629
Low-carbon ferrochromium	68	272	17	289
Ferrochromium-silicon	82	52	1	53
Chromium metal	18	3	—	3

Source: Defense Logistics Agency.

to meet anticipated domestic demand under mobilization conditions. To ensure prompt NDS response to a national defense emergency, the President chose to convert stockpiled chromite ore to ferrochromium. Changes in industrial capacity and new manufacturing and technological developments have rendered selected chromium materials in the NDS inventory obsolete, either in quality or form or both, and in need of upgrading. Subsequent to legislative mandate, DLA began modernizing chromium materials in the NDS by converting nonspecification-grade low-carbon ferrochromium into chromium metal. (See Legislation and Government Programs section of this report.)

Issues

World ferrochromium production capacity in 1990 increased significantly. Strong demand for ferrochromium, resulting from high levels of stainless steel production worldwide in 1987-89, resulted in ferrochromium plant expansions and new plant construction. Since 1970, the trend has been for ferrochromium production capacity to move from major stainless steel-producing countries (e.g., Japan, Western Europe, and the United States) to major chromite ore-producing countries (e.g., Finland, the Philippines, the Republic of South Africa, Turkey, and Zimbabwe). This has occurred through the creation of new plants or furnaces in chromite ore-producing locations and the closure of furnaces in other geographic areas where ferrochromium

production was formerly strong. The increase in and change in location of world annual gross weight production capacity, including net expansion by about 400,000 tons in 1989 and about 240,000 tons in 1990, has continued that trend. (Some new production facilities were completed but not put into production. Thus, there are production facilities that could be started up quickly, resulting in prompt production expansion when it is needed.) About 80% of added capacity was in chromite ore-producing countries in 1989 and 100% in 1990. All of capacity contraction was in nonchromite-producing countries. The largest addition to national annual capacity was in the Republic of South Africa, where about 120,000 tons was added in 1989 and 280,000 tons was added in 1990, increasing The Republic of South Africa's capacity by about 30% in the 1989-90 time period. The supply shortage in 1988 was estimated to have been about 200,000 tons or about 5% of 1988 world production capacity. The expansion of 1989 and 1990 represented about 16% of 1988 world production capacity.

Stainless steel is the major chromium end use. In 1990, reduced demand for ferrochromium, resulting from decreased stainless steel production, and increased supply of ferrochromium, resulting from producer expansions and new plant construction, caused excess ferrochromium production capacity. Despite strong demand for ferrochromium resulting from production of stainless steel, excess ferrochromium production capacity caused

declining ferrochromium prices since their peak values in 1988. In 1990, world ferrochromium production was limited by delaying the startup of new furnaces, the idling of some furnaces, the conversion of some furnaces from ferrochromium to other ferroalloy production, and the closure of one plant.

Thus, by mid-1990, a combination of marginally reduced demand and added production capacity resulted in a large imbalance between demand and production capacity. With stainless steel production growing at a long-term average annual rate of 3% to 4%, it is estimated that it will take about 5 years for demand to catch up with added capacity. Experience shows that short-term variations in chromium consumption and production can be significantly larger than long-term trends.

Production

The major marketplace chromium materials are chromite ore and chromium metal, ferroalloys, and chemicals. In 1990, the United States produced chromium metal, ferroalloys, and chemicals, but no chromite ore.

Chrome Corp. of America, a subsidiary of Boulder Gold (Australia), entered a joint venture with Phelps Dodge to explore chromite at the Stillwater Complex (Montana) and to study the possibility for mining and producing ferrochromium. The study was planned to be completed in 1991. Chrome Corp. estimated that production could start in 1993.

Macalloy Corp. converted chromite ore to high-carbon ferrochromium for the NDS under a contract with the DLA. Elkem Metals Co. converted nonspecification-grade low-carbon ferrochromium into chromium metal for the NDS under a contract with the DLA. (See Legislation and Government Programs section of this report.)

Consumption and Uses

Domestic consumption of chromite ore and concentrate was 402,290 tons in 1990. Of the total chromite consumed, the chemical and metallurgical industry used 358,620 tons, and the refractory industry, 43,670. Much of the chromite consumed and ferrochromium produced by the metallurgical industry were part of the NDS conversion program. (See Legislation and Government Programs section of this report.)

TABLE 10

PRINCIPAL U.S. PRODUCERS OF CHROMIUM PRODUCTS IN 1990, BY INDUSTRY

Industry and company	Plant
Metallurgical:	
Elkem AS, Elkem Metals Co.	Marietta, OH, and Alloy, WV.
Macalloy Corp.	Charleston, SC.
Satra Concentrates Inc.	Steubenville, OH.
SKW Alloys Inc.	Calvert City, KY, and Niagara Falls, NY.
Refractory:	
General Refractories Co.	Lehi, UT.
Harbison-Walker Refractories, a division of Dresser Industries Inc.	Hammond, IN.
National Refractories & Mining Corp.	Moss Landing, CA, and Columbiana, OH.
North American Refractories Co. Ltd.	Womelsdorf, PA.
Chemical:	
American Chrome & Chemicals Inc.	Corpus Christi, TX.
Occidental Chemicals Corp.	Castle Hayne, NC.

TABLE 11

PRODUCTION, SHIPMENTS, AND STOCKS OF CHROMIUM FERROALLOYS AND CHROMIUM METAL IN THE UNITED STATES (Metric tons)

Year	Net production		Net shipments	Producer stocks, Dec. 31
	Gross weight	Chromium content		
1986	95,624	58,913	104,924	12,796
1987	106,716	68,614	114,734	5,114
1988	119,645	73,282	115,499	8,831
1989	146,844	90,073	135,361	20,475
1990	108,932	67,701	91,735	14,935

TABLE 12

CONSUMPTION OF CHROMITE AND TENOR OF ORE USED BY PRIMARY CONSUMER GROUPS IN THE UNITED STATES

Year	Chemical and metallurgical industry		Refractory industry		Total ¹	
	Gross weight (metric tons)	Average Cr ₂ O ₃ (percentage)	Gross weight (metric tons)	Average Cr ₂ O ₃ (percentage)	Gross weight (metric tons)	Average Cr ₂ O ₃ (percentage)
1986	342,281	40.3	45,303	37.1	387,584	40.2
1987	458,536	41.0	47,586	39.9	506,122	40.9
1988	494,713	42.8	55,923	38.9	550,636	42.4
1989	516,931	42.8	43,780	39.5	560,711	42.6
1990	358,620	40.5	43,670	39.7	402,290	40.1

¹Data may not add to totals shown because of independent rounding.

Chromium has a wide range of uses in the three primary consumer groups. In the metallurgical industry, its principal use in 1990 was in stainless steel. Of the 388,916 tons of chromium ferroalloys, metal, and other chromium-containing materials reported consumed, stainless steel accounted for 78%; full-alloy steel, 9%; and other end uses, 13%. The primary use of chromium in the refractory industry was in the form of chromite to make refractory bricks to line metallurgical furnaces. Chromite consumption by the refractory industry decreased to 43,670 tons.

The chemical industry consumed chromite for manufacturing sodium bichromate, chromic acid, and other chromium chemicals and pigments. Sodium bichromate is the material from which a wide range of chromium chemicals are made.

Stocks

Reported consumer stocks of chromite in the United States decreased from 392,273 tons in 1989 to 354,661 tons in 1990. Chemical and metallurgical industry stocks decreased as did refractory industry stocks. At the 1990 annual rate of chromite consumption, consumer stocks represented about 11 months of supply in the chemical and metallurgical industry and 6 months of supply in the refractory industry. Producer stocks of chromium ferroalloys, metal, and other materials decreased from 20,475 tons in 1989 to 14,935 tons in 1990. Consumer stocks decreased from 19,486 tons in 1989 to 17,371 tons in 1990. At the 1990 annual rate of chromium ferroalloy and metal consumption, producer plus consumer stocks represented about a 5-week supply.

Prices

The price of chromite decreased steadily in 1990. The published price of the Republic of South African Transvaal chromite, 44% Cr₂O₃ (no specific chromium-to-iron ratio), decreased from a range of \$60 to \$65 per ton, f.o.b. the Republic of South African ports, to a range of \$55 to \$60 in June and a range of \$50 to \$55 in November, where it remained for the rest of the year. The published price of Turkish ore started the year by decreasing from a range of \$175 to \$185 per ton, f.o.b. Turkish ports, to a range of \$160 to \$170 in January. It then decreased to a range of \$145 to \$160

TABLE 13
**U.S. CONSUMPTION OF CHROMIUM FERROALLOYS AND METAL, BY
END USE**
(Metric tons, gross weight)

End use	Ferrochromium		Ferro- chromium- silicon	Other	Total ³
	Low- carbon ¹	High- carbon ²			
1989:					
Steel:					
Carbon	2,990	3,963	207	W	7,160
Stainless and heat-resisting	8,274	^r 264,933	6,837	^r 195	280,240
Full-alloy	4,997	25,589	1,263	W	31,849
High-strength, low-alloy and electric	1,928	^r 2,445	8,036	W	12,408
Tool	845	3,318	W	W	4,164
Cast irons	597	^r 6,500	26	W	7,123
Superalloys	^r 3,538	4,551	—	^r 3,243	11,333
Welding materials ⁴	432	583	—	136	1,151
Other alloys ⁵	^r 1,067	^r 772	—	^r 1,989	3,830
Miscellaneous and unspecified	313	131	45	410	899
Total ^{3 6}	^r 24,983	^r 312,786	16,415	^r 75,974	^r 360,157
Chromium content	^r 17,206	^r 185,752	5,901	^r 4,776	^r 213,636
Stocks, Dec. 31, 1989	^r 4,397	^r 14,141	425	^r 8523	^r 19,486
1990:					
Steel:					
Carbon	3,192	4,079	276	W	7,547
Stainless and heat-resisting	7,100	287,665	7,929	151	302,845
Full-alloy	4,171	29,326	1,325	W	34,822
High-strength, low-alloy and electric	1,977	2,905	W	W	4,882
Tool	903	2,797	W	—	3,700
Cast irons	W	5,590	26	W	5,616
Superalloys	3,856	4,443	—	3,942	12,241
Welding materials ⁴	439	W	—	140	579
Other alloys ⁵	1,137	385	—	1,742	3,263
Miscellaneous and unspecified	3,865	876	8,103	579	13,422
Total ^{3 6}	26,639	338,065	17,659	⁹ 6,553	388,916
Chromium content	17,927	193,944	6,347	5,552	223,770
Stocks, Dec. 31, 1990	3,280	12,923	455	¹⁰ 712	17,371

^rRevised. W Withheld to avoid disclosing company proprietary data; included with "Miscellaneous and unspecified."

¹Low-carbon ferrochromium contains less than 3% carbon.

²High-carbon ferrochromium contains 3% or more carbon.

³Data may not add to totals shown because of independent rounding of converted units.

⁴Includes structural and hard-facing welding material.

⁵Includes cutting materials and magnetic, aluminum, copper, nickel, and other alloys.

⁶Includes estimates.

⁷Includes 4,290 tons of chromium metal.

⁸Includes 330 tons of chromium metal.

⁹Includes 4,920 tons of chromium metal.

¹⁰Includes 497 tons of chromium metal.

in June, followed by a further decrease in November to a range of \$120 to \$135, where it remained for the rest of the year.

Ferrochromium prices declined in 1990 as significant ferrochromium production

reductions were implemented to help move ferrochromium production and consumption toward balance. The published price of domestic high-carbon ferrochromium (50% to 55% chromium)

increased from 50.25 to 54.5 cents per pound (¢/lb) of chromium content in January, where it remained for the rest of the year. The published price of domestic low-carbon [0.05% and 0.015% (Simplex) carbon] ferrochromium remained unchanged. The published price of domestic chromium metal declined. The published price of electrolytic chromium metal declined from 395 ¢/lb to 350 ¢/lb in January, after which it increased to 370 ¢/lb, where it remained for the rest of the year. The price of elchrome declined from 462 ¢/lb to 422.5 ¢/lb in August, where it remained for the rest of the year. (Elchrome is a vacuum degassed chromium metal product produced by Elkem Metals Co.)

The price of imported high-carbon (50% to 55% and 60% to 65% chromium) ferrochromium declined until November, when it made a marginal recovery. The published price of imported 50% to 55% high-carbon ferrochromium started the year at a range of 50 to 52.25 ¢/lb-Cr from which it declined to a low range of 45 to 46 ¢/lb-Cr in November, after which it increased to a range of 46 to 47.5 ¢/lb-Cr. The published price of imported 60% to 65% high-carbon ferrochromium started the year at a range of 51 to 54.5 ¢/lb-Cr from which it declined to a range of 42.25 to 45.5 ¢/lb-Cr in December. The published price of imported low-carbon (0.05% carbon) ferrochromium varied throughout the year.

Foreign Trade

Chromium material exports from and imports to the United States included chromite ore and chromium metal, ferroalloys, chemicals, and pigments.

World Review

The council of the Chromium Association (Republic of South Africa) and the directors of the Chromium Centre (France) merged their respective organizations into a single organization, the International Chromium Development Association (ICDA). Each organization had been in operation for 6 years. The objective of the new organization is to promote the growth of chromium use in its traditional markets and the development of new end-use markets. Stainless steel in general and ferritic stainless steel in particular have been materials targeted for development. Structural and corrosion resistant end uses were the targeted

TABLE 14

U.S. CONSUMER STOCKS OF CHROMITE, CHROMIUM FERROALLOYS, AND METAL, DECEMBER 31

(Metric tons, gross weight)

Industry	1986	1987	1988	1989	1990
Chromite:					
Chemical and metallurgical	249,291	308,870	366,268	368,482	333,224
Refractory	35,379	23,144	23,353	23,791	21,437
Total	<u>284,670</u>	<u>332,014</u>	<u>389,621</u>	<u>392,273</u>	<u>354,661</u>
Chromium ferroalloy and metal:					
Low-carbon ferrochromium	4,985	3,169	5,683	[†] 4,397	3,280
High-carbon ferrochromium	20,840	18,023	23,135	[†] 14,141	12,923
Ferrochromium-silicon	1,324	505	647	425	455
Other ¹	1,607	826	960	[†] 523	712
Total ²	<u>28,756</u>	<u>22,524</u>	<u>30,425</u>	<u>[†]19,486</u>	<u>17,371</u>

[†]Revised.¹Includes chromium briquets, chromium metal, exothermic chromium additives, and other miscellaneous chromium alloys.²Data may not add to totals shown because of independent rounding.

TABLE 15

PRICE QUOTATIONS FOR CHROMIUM MATERIALS AT BEGINNING AND END OF 1990

Material	January	December
	Dollars per metric ton of product	
Chromite ore:		
South Africa, Republic of	60 - 65	50 - 55
Turkey	160 -170	120 -135
	Cents per pound of chromium	
High-carbon ferrochromium:		
Domestic: 50% to 55% chromium	50.25	54.5
Imported:		
50% to 55% chromium	52 - 55.5	46 - 47.5
60% to 65% chromium	51 - 54.5	42.25- 45.5
Low-carbon:		
Domestic:		
0.05% carbon	95	95
0.015% carbon (Simplex)	166	166
Imported: 0.05% carbon	94 -105	98 -105
	Cents per pound of product	
Chromium metal (domestic):		
Electrolytic	395.0	370.0
Elchrome	462.0	422.5

Source: Metals Week.

markets. The Chromium Review and bi-monthly news bulletins are the communication tools to be used by the new organization. The ICDA has offices in Paris, France, and Johannesburg, the Republic of South Africa.

The German Ministry of Economic Affairs, in cooperation with the World Mining Congress, reviewed the world chromium industry. Information on company, location, product quality, geology and resources, and mining

methods were prepared by country and mine.¹⁴

Industry Structure.—The chromium industry is composed primarily of chromite ore producers, ferrochromium producers, and stainless steel producers. Other industry components are chromium chemical and chromite refractory producers.

Brazil, Finland, India, the Republic of South Africa, and the U.S.S.R. are countries that mine chromite, produce ferrochromium, and produce stainless steel. In Finland, Outokumpu Oy, a major share of which is state-owned, owns and operates chromite mining, ferrochromium production, and stainless steel production facilities, making it completely vertically integrated. In the Republic of South Africa, Barlow Rand, an investment company, owns chromite mining operations (Rand Mines) and ferrochromium and stainless steel production facilities (Middelburg Steel and Alloys), making it the only completely vertically integrated chromium producer in the Republic of South Africa. Gencor, an investment company, owns chromite mining operations and ferrochromium production facilities through South Africa Manganese Amcor Ltd. (Saman-cor). Samancor owns chromite mining operations through its subsidiary Cromore and owns ferrochromium smelters (Tubatse and Ferrometals). Anglovaal, an investment company, owns chromite mines through Associated Ore and Metal Corp., which operates a ferrochromium smelter (Feralloys) through Associated Manganese Mines. Anglo American and Johannesburg Consolidated Investment, investment companies, have shared interests in chromite mines and ferrochromium smelters (Consolidated Metallurgical Industries and Purity Ferrochrome). One other company in the Republic of South Africa, Chromecorp Technology, has chromite mining and ferrochromium production operations. Chromium chemical and chromite refractory production in the Republic of South Africa is also vertically integrated from mine production through product production. Bayer AG (Federal Republic of Germany) owns a chromite mine and chromium chemical plant. Vereening Refractories operates a chromite mine and produces chromite refractories. In the Republic of South Africa, the chromium-related companies are privately owned. Typically, major shares of a company are owned by other

TABLE 16
U.S. EXPORTS AND REEXPORTS OF CHROMITE ORE
AND CONCENTRATES

Year	Exports		Reexports	
	Quantity (metric tons)	Value (thou- sands)	Quantity (metric tons)	Value (thou- sands)
1986	83,559	\$4,143	1,322	\$511
1987	1,145	707	4,837	352
1988	3,931	1,430	1,032	320
1989	40,445	5,014	2,375	351
1990	6,321	1,488	4,052	513

Source: Bureau of the Census.

TABLE 17
U.S. EXPORTS OF CHROMIUM MATERIALS, BY TYPE

Type	1988	1989	1990		Principal destinations, 1990
	Gross weight (metric tons)	Gross weight (metric tons)	Gross weight (metric tons)	Value (thou- sands)	
Chromite ore and concentrate	3,931	40,445	6,321	\$1,488	Canada (78%); Mexico (11%); Pakistan (6%).
Metal and alloys:					
Chromium metal ¹	318	196	338	3,447	Japan (47%); Canada (25%); Netherlands (10%); Mexico (7%).
Chromium ferroalloys:					
High-carbon ferrochromium	² 38,041	² 49,464	⁵ 5,795	5,728	Mexico (55%); Canada (43%).
Low-carbon ferrochromium	—	—	⁶ 2,521	3,782	Canada (53%); Mexico (28%); Argentina (7%); Japan (3%); Venezuela (3%).
Ferrochromium-silicon	—	—	⁷ 802	1,027	Canada (94%); Mexico (5%).
Chemicals:					
Chromium oxides:					
Chromium trioxide ⁸	4,174	3,929	4,082	9,811	Canada (33%); Japan (22%); Republic of Korea (9%); Venezuela (9%); Mexico (5%); Taiwan (5%).
Other	NA	448	1,226	4,590	Canada (31%); Mexico (24%); Japan (12%); Republic of South Africa (8%); Italy (6%); United Kingdom (6%).
Chromium sulfates	NA	1	44	68	Mexico (56%); Canada (44%).
Salts of oxometallic or peroxometallic acids:					
Zinc and lead chromate	NA	152	209	567	Mexico (42%); Canada (22%).
Sodium dichromate ⁹	19,977	18,556	16,663	10,611	Italy (41%); Thailand (16%); Colombia (13%); China (7%); Republic of Korea (4%); Taiwan (4%); Mexico (3%); Indonesia (2%).
Potassium dichromate ¹⁰	27	46	48	95	Mexico (29%); Canada (27%); Honduras (22%); Indonesia (11%); Japan (3%).
Other chromates, dichromates, and peroxochromates	NA	171	228	707	United Kingdom (61%); Canada (15%); Colombia (13%).
Pigments and preparations	3,239	2,264	2,643	9,252	Canada (22%); Philippines (21%); Singapore (11%); Federal Republic of Germany (10%).

NA Not available.

¹Wrought and unwrought and waste and scrap in 1988. Articles thereof and waste and scrap in 1989.

²Includes high-, medium-, and low-carbon ferrochromium and ferrochromium-silicon.

³Contained 4,845 tons of chromium.

⁴Contained 5,647 tons of chromium.

⁵Contained 3,477 tons of chromium.

⁶Contained 1,517 tons of chromium.

⁷Contained 333 tons of chromium.

⁸Chromic acid in 1988.

⁹Included sodium chromate in 1988.

¹⁰Included potassium chromate in 1988.

Source: Bureau of the Census.

companies, and the remainder, if any, is openly traded. (See figure 3.)

In Brazil, the mining and smelting of chromium is vertically integrated, but stainless steel production is independent of the mining-smelting operations. The major mining companies are subsidiaries of Cia. de Ferro Ligas da Bahia S.A. (FERBASA). Stainless steel is produced primarily by Companhia Aços Especiais Itabira (ACESITA). Other chromite operations in Brazil are also vertically integrated. Bayer AG (Federal Republic of Germany) owns a chromite mine and chromium chemical plant. Refractory chromite operations are also vertically

TABLE 18
U.S. IMPORTS FOR CONSUMPTION OF CHROMITE, BY COUNTRY

Country	Not more than 40% Cr ₂ O ₃			More than 40% but less than 46% Cr ₂ O ₃			46% or more Cr ₂ O ₃			Total ¹		
	Gross weight (metric tons)	Cr ₂ O ₃ content (metric tons)	Value (thou-sands)	Gross weight (metric tons)	Cr ₂ O ₃ content (metric tons)	Value (thou-sands)	Gross weight (metric tons)	Cr ₂ O ₃ content (metric tons)	Value (thou-sands)	Gross weight (metric tons)	Cr ₂ O ₃ content (metric tons)	Value (thou-sands)
1989:												
Canada	27	5	\$2	—	—	—	18	4	\$4	45	9	\$6
Japan	—	—	—	—	—	—	4,498	2,024	360	4,498	2,024	360
New Caledonia	—	—	—	—	—	—	3,500	1,921	529	3,500	1,921	529
Pakistan	4,025	1,490	322	5,522	2,414	\$911	3,117	1,434	608	12,664	5,338	1,841
Philippines	17,030	6,396	1,694	—	—	—	4,841	2,490	525	21,871	8,886	2,219
South Africa, Republic of	74,219	28,217	4,654	133,432	59,870	9,680	159,917	80,225	11,339	367,568	168,312	25,673
Turkey	36,500	13,185	3,412	36,450	15,222	4,783	30,732	17,159	4,290	103,682	45,566	12,485
U.S.S.R.	6,478	2,494	264	—	—	—	4,738	2,388	574	11,216	4,882	838
Total ¹	138,279	51,787	10,347	175,404	77,506	15,373	211,361	107,645	18,228	525,044	236,938	43,949
1990:												
Canada	54	15	\$5	—	—	—	12	9	\$5	66	24	\$10
Indonesia	—	—	—	20	8	4	—	—	—	20	8	4
New Caledonia	—	—	—	—	—	—	2,200	1,224	413	2,200	1,224	413
Pakistan	—	—	—	—	—	—	40	24	8	40	24	8
Philippines	13,133	4,716	1,533	—	—	—	522	269	37	13,655	4,985	1,570
South Africa, Republic of	10,806	1,859	615	129,617	59,025	9,216	120,103	55,885	8,545	260,526	116,769	18,376
Turkey	25,500	9,150	1,214	—	—	—	3,500	1,610	555	29,000	10,760	1,769
Total ¹	49,493	15,740	3,367	129,636	59,033	9,219	126,377	59,021	9,563	305,507	133,794	22,150

^aEstimated.

¹Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 19
U.S. IMPORTS FOR CONSUMPTION OF FERROCHROMIUM, BY COUNTRY

Country	Low-carbon (not more than 3% carbon)			Medium-carbon (more than 3% carbon but not more than 4% carbon)			High-carbon (more than 4% carbon)			Total (all grades)		
	Gross weight (metric tons)	Chromium content (metric tons)	Value (thou-sands)	Gross weight (metric tons)	Chromium content (metric tons)	Value (thou-sands)	Gross weight (metric tons)	Chromium content (metric tons)	Value (thou-sands)	Gross weight (metric tons)	Chromium content (metric tons)	Value (thou-sands)
1989:												
Australia	—	—	—	—	—	—	243	149	\$156	243	149	\$156
Belgium ^f	48	25	\$68	—	—	—	—	—	—	48	25	68
Brazil	—	—	—	—	—	—	5,803	3,130	5,236	5,803	3,130	5,236
Canada	45	26	61	—	—	—	—	—	—	45	26	61
Chile	67	44	96	40	26	\$45	500	341	613	607	411	753
China	1,241	887	1,522	146	78	78	20,582	13,175	19,292	21,970	14,140	20,892
France	—	—	—	—	—	—	5	3	13	5	3	13
Germany, Federal Republic of	9,956	7,100	18,654	—	—	—	238	149	438	10,194	7,250	19,091
Greece	—	—	—	—	—	—	750	488	952	750	488	952

See footnotes at end of table.

TABLE 19—Continued

U.S. IMPORTS FOR CONSUMPTION OF FERROCHROMIUM, BY COUNTRY

Country	Low-carbon (not more than 3% carbon)			Medium-carbon (more than 3% carbon but not more than 4% carbon)			High-carbon (more than 4% carbon)			Total (all grades)		
	Gross weight (metric tons)	Chromium content (metric tons)	Value (thou- sands)	Gross weight (metric tons)	Chromium content (metric tons)	Value (thou- sands)	Gross weight (metric tons)	Chromium content (metric tons)	Value (thou- sands)	Gross weight (metric tons)	Chromium content (metric tons)	Value (thou- sands)
1989—Continued												
India	—	—	—	—	—	—	4,770	3,032	5,806	4,770	3,032	5,806
Italy	1,328	872	1,972	—	—	—	2,500	1,540	2,838	3,828	2,412	4,810
Japan	365	261	1,040	101	66	182	853	557	1,076	1,319	884	2,298
Mexico	—	—	—	—	—	—	3,019	1,754	2,296	3,019	1,754	2,296
Philippines	—	—	—	7,108	4,727	8,825	8,382	5,129	6,938	15,489	9,856	15,762
South Africa, Republic of	8,887	5,277	10,717	6,209	3,941	7,019	124,070	64,662	95,743	139,165	73,880	113,479
Spain	—	—	—	—	—	—	374	251	260	374	251	260
Sweden	3,797	3,006	3,982	—	—	—	8,750	5,009	7,481	12,546	8,015	11,463
Taiwan	—	—	—	—	—	—	1,215	668	1,149	1,215	668	1,149
Turkey	3,434	2,376	5,036	—	—	—	36,204	23,143	33,054	39,639	25,519	38,090
United Kingdom	73	52	128	—	—	—	34	18	22	107	70	150
Yugoslavia	256	169	363	—	—	—	30,625	19,311	30,975	30,881	19,480	31,337
Zimbabwe	7,684	5,177	7,131	17,300	11,276	19,710	26,732	17,501	29,465	51,716	33,953	56,305
Total ¹	37,181	25,272	50,769	30,903	20,114	35,858	275,650	160,010	243,800	343,733	205,396	330,427
1990:												
Albania	—	—	—	—	—	—	1,505	961	689	1,505	961	689
Australia	—	—	—	—	—	—	294	179	84	294	179	84
Brazil	300	177	321	—	—	—	1,250	659	523	1,550	836	844
Canada	1	—	2	—	—	—	44	23	23	45	23	25
China	350	225	401	—	—	—	1,270	797	766	1,620	1,022	1,167
Finland	—	—	—	—	—	—	23,849	12,530	12,067	23,849	12,530	12,067
France	90	67	149	—	—	—	884	596	591	974	663	740
Germany, Federal Republic of	11,997	8,498	22,195	—	—	—	47	29	92	12,044	8,527	22,287
Greece	—	—	—	—	—	—	240	157	224	240	157	224
Italy	955	686	1,864	—	—	—	—	—	—	955	686	1,864
Japan	364	251	865	193	131	333	387	263	720	944	645	1,918
Mexico	—	—	—	—	—	—	11	6	6	11	6	6
Norway	—	—	—	—	—	—	21,490	13,067	10,865	21,490	13,067	10,865
Philippines	2,554	1,660	1,379	—	—	—	11,793	6,781	4,826	14,347	8,441	6,205
South Africa, Republic of	9,599	5,790	9,703	19,702	10,251	9,095	143,067	74,491	63,033	172,368	90,532	81,831
Spain	—	—	—	—	—	—	1,531	1,008	961	1,531	1,008	961
Sweden	181	135	586	—	—	—	11,821	6,713	5,621	12,002	6,848	6,207
Turkey	9,670	6,716	11,424	—	—	—	35,650	22,353	19,871	45,320	29,069	31,295
United Kingdom	238	159	359	—	—	—	320	139	201	558	298	560
Yugoslavia	—	—	—	—	—	—	48,904	30,975	25,885	48,904	30,975	25,885
Zimbabwe	9,761	6,118	9,050	5,057	3,315	3,801	40,525	26,448	27,863	55,343	35,881	40,714
Total ¹	46,059	30,485	58,299	24,952	13,696	13,230	344,882	198,175	174,911	415,893	242,356	246,439

¹Revised.¹Data may not add to totals shown because of independent rounding.

Source: Bureau of the Census.

TABLE 20
U.S. IMPORTS OF CHROMIUM MATERIALS, BY TYPE

Type	1988	1989	1990		Principal sources, 1990
	Gross weight (metric tons)	Gross weight (metric tons)	Gross weight (metric tons)	Value (thousands)	
METALS AND ALLOYS					
Chromium metal:					
Waste and scrap	NA	50	85	\$475	China (75%); Hong Kong (24%).
Other than waste and scrap ¹	4,101	4,152	6,579	42,686	China (30%); Japan (29%); France (19%); United Kingdom (19%).
Ferrochromium-silicon	² 9,710	³ 6,803	⁴ 3,801	2,616	Zimbabwe (100%).
CHEMICALS					
Chromium oxides and hydroxides:					
Chromium trioxide ⁵	1,542	661	1,677	3,502	Federal Republic of Germany (27%); Netherlands (21%); Japan (19%); United Kingdom (15%); Italy (6%).
Other ⁶	NA	3,880	3,512	11,018	Federal Republic of Germany (38%); United Kingdom (19%); China (6%); Canada (4%).
Sulfates of chromium	NA	313	192	176	United Kingdom (40%); Turkey (36%); Mexico (12%); Italy (10%).
Salts of oxometallic or peroxometallic acids:					
Chromates of lead and zinc	NA	607	425	859	Poland (48%); Federal Republic of Germany (18%); Norway (17%); Japan (14%).
Sodium dichromate ⁷	3,756	5,489	1,661	1,548	Mexico (37%); Republic of South Africa (31%); Turkey (12%); Spain (7%).
Potassium dichromate ⁷	1,327	827	680	1,264	U.S.S.R. (34%); United Kingdom (32%); Federal Republic of Germany (28%).
Other chromates and dichromates; peroxochromates	NA	1,010	1,860	4,491	United Kingdom (63%); Italy (28%).
Chromium carbide	68	108	123	1,278	Federal Republic of Germany (62%); United Kingdom (19%); Japan (18%).
PIGMENTS AND PREPARATIONS BASED ON CHROMIUM					
Chrome yellow	3,999	3,688	3,643	7,636	Canada (72%); Hungary (19%).
Molybdenum orange	1,131	1,046	916	2,579	Canada (97%); Japan (1%); France (1%).
Zinc yellow	1,098	542	436	880	Norway (92%); Canada (4%); Poland (4%).
Other ⁸	NA	687	657	2,613	Federal Republic of Germany (56%); Japan (23%); Canada (11%); Romania (6%); United Kingdom (3%).

NA Not available.

¹Includes wrought and unwrought and waste and scrap before 1989.

²Contained 3,885 tons of chromium.

³Contained 2,756 tons of chromium.

⁴Contained 1,459 tons of chromium.

⁵Called chromic acid before 1989.

⁶Includes material reported as chromium oxide green or hydrated chromium oxide green before 1989.

⁷Included chromates before 1989 that are reported under "Other" in 1989.

⁸Includes material reported under chrome green, chromium oxide green, hydrated chromium green, or strontium chromate before 1989.

Source: Bureau of the Census.

integrated from chromite production through refractory material production. Chromite mining and ferrochromium production in India is mostly vertically integrated. Ferro Alloys Corp. is the only one of many stainless steel producers in

India that is integrated from chromite ore mining through ferrochromium and stainless steel production. In the U.S.S.R., chromite mining, ferrochromium production, and stainless steel production are state-owned.

The chromium industry of Japan consists primarily of the production of ferrochromium and stainless steel. Chromite ore production in Japan is small relative to consumption. In Japan, industrial companies may group together to meet

TABLE 21
U.S. IMPORT DUTIES FOR CHROMIUM-CONTAINING MATERIALS IN 1990

Item	Harmonized Tariff Schedule No.	Most favored nation (MFN)	Non-MFN	Special	
				CA ¹	A, E, IL ²
Chromite ores and concentrates therefrom:					
Not more than 40% Cr ₂ O ₃	2610.00.0020	Free	Free	NA	Free
More than 40% and less than 46% Cr ₂ O ₃	2610.00.0040	do.	do.	Free	Do.
Not less than 46% Cr ₂ O ₃	2610.00.0060	do.	do.	do.	Do.
Chromium oxides and hydroxides:					
Chromium trioxide	2819.10.0000	3.7% ad valorem	25% ad valorem	do.	Do.
Other	2819.90.0000	do.	do.	do.	Do.
Sulfates; alums; peroxosulfates (persulfates):					
Other sulfates: of chromium	2833.23.0000	do.	do.	1.9% ad valorem	Do.
Salts of oxometallic or peroxometallic acids:					
Chromates of zinc and lead	2841.20.0000	do.	do.	2.2% ad valorem	Do.
Sodium dichromate	2841.30.0000	2.4% ad valorem	8.5% ad valorem	1.4% ad valorem	Do.
Potassium dichromate	2841.40.0000	1.5% ad valorem	3.5% ad valorem	0.9% ad valorem	Do.
Other chromates and dichromates; peroxochromates	2841.50.0000	3.1% ad valorem	25% ad valorem	1.8% ad valorem	Do.
Carbides, whether or not chemically defined:					
Other: of chromium	2849.90.2000	4.2% ad valorem	do.	2.5% ad valorem	Do.
Pigments and preparations based on chromium:					
Chrome yellow	3206.20.0010	3.7% ad valorem	do.	2.2% ad valorem	Do.
Molybdenum orange	3206.20.0020	do.	do.	do.	Do.
Zinc yellow	3206.20.0030	do.	do.	do.	Do.
Other	3206.20.0050	do.	do.	do.	Do.
Metal and alloys: Ferrochromium:					
More than 4% carbon	7202.41.0000	1.9% ad valorem	7.5% ad valorem	Free	Do.
More than 3% and not more than 4% carbon	7202.49.1000	do.	do.	do.	Do.
Other (i.e., not more than 3% carbon)	7202.49.5000	3.1% ad valorem	30% ad valorem	do.	Do.
Ferrosilicon chromium	7202.50.0000	10% ad valorem	25% ad valorem	do.	Do.
Other base metals; cermets; articles thereof:					
Chromium:					
Waste and scrap	8112.20.3000	Free	Free	NA	Do.
Other	8112.20.6000	3.7% ad valorem	30% ad valorem	2.2% ad valorem	Do.

NA Not available.

¹United States-Canada Free Trade Agreement. These tariff values became effective Jan. 1, 1990.

²A—Generalized System of Preferences, E—Caribbean Basin Economic Recovery Act, IL—United States-Israel Free-Trade Area Implementation Act of 1985.

Source: U.S. International Trade Commission. Harmonized Tariff Schedule of the United States (1990). USITC Publication 2232.

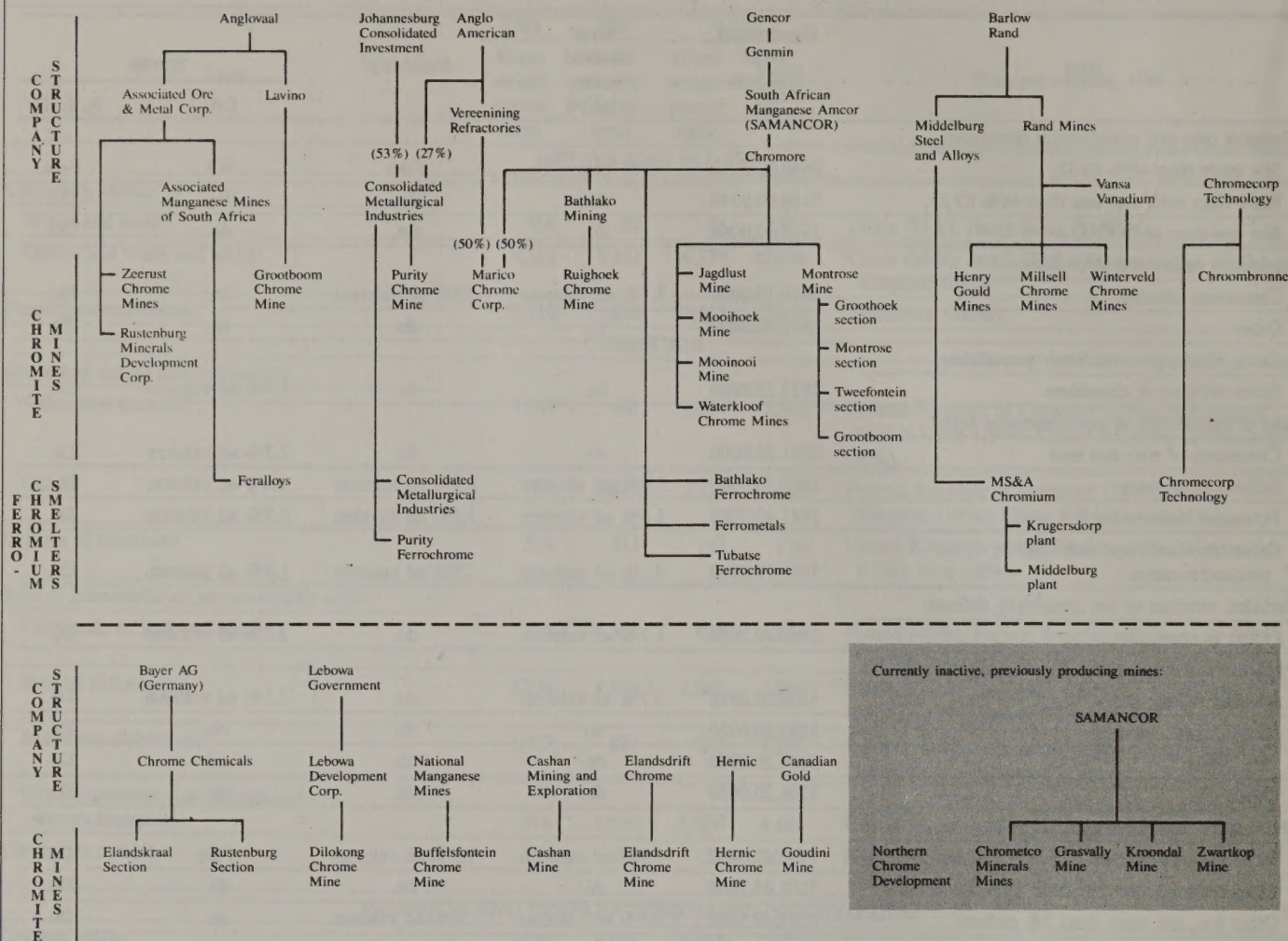
common needs such as insurance, banking, transportation, international trade, real estate, etc. Companies within a group are frequently part owners of other companies within the group, but shareholding between groups is also common, especially by banking and trust companies. The Japanese ferrochromium producers are typically associated with stainless steel producers and may be part

of a group. Association means the stainless steel producer takes the output of the ferrochromium producer. Because Japanese industry is typically both forward and backward integrated, stainless steel and ferrochromium may each be partial owners of one another. The chromium industry of Turkey is composed of both large and small chromite ore producers, with one major producer,

Etibank, integrated from mining through ferrochromium production. The chromium industry of Zimbabwe is composed of large companies vertically integrated from chromite mine production through ferrochromium production, small independent chromite mines, and chromite mines operated independently on behalf of the large vertically integrated companies.

FIGURE 3

STRUCTURE OF THE SOUTH AFRICAN CHROMIUM INDUSTRY IN 1990



Sources: Minerals Bureau (South Africa). South Africa's Minerals Industry 1989, pp. 79-85, Sept. 1990.
 Minerals Bureau (South Africa). Operating Mines, Quarries and Mineral Processing Plants in the Republic of South Africa, Directory D1/90, #57-87, July 1990.
 Minerals Bureau (South Africa). Ferrous Mineral Commodities produced in the Republic of South Africa, Directory D8/88, 1988, pp. 1-11, 23-28.
 M. H. Silk. World Chromite Resources and Ferrochromium Production. Council for Mineral Technology Special Publication No. 11, 1988, 149 pp.
 Company annual reports.

Capacity.—The data in table 15 are rated capacities for major countries that mine chromite ore and produce ferrochromium, primary chromium chemicals, and chromium metal as of December 31, 1990. Rated capacity is defined as the maximum quantity of product that can be produced in a period of time at a normally sustainable long-term operating rate, based on the physical equipment

of the plant, and given acceptable routine operating procedures involving labor, energy, materials, and maintenance. Capacity includes both operating plants and plants temporarily closed that, in the judgment of the author, can be brought into production within a short period of time with minimum capital expenditure. Because not all countries or producers make production capacity information

available, historical chromium trade data have been used to estimate production capacity. Rated production capacity changes result both from changes in facilities and changes in knowledge about facilities.

Reserves.—The United States has no chromite ore reserves. However, the United States has a reserve base and resources that could be exploited. (For

TABLE 22

WORLD CHROMIUM RESOURCES¹ AND ANNUAL PRODUCTION CAPACITY OF CHROMITE ORE, FERROCHROMIUM, CHROMIUM METAL, AND CHROMIUM CHEMICALS IN 1990

(Thousand metric tons, contained chromium)

	Resources ²			Annual production capacity			
	Reserves	Reserve base ³	Identified resources	Ore	Ferro-chromium	Metal	Chem-icals
Albania	1,900	1,900	6,300	218	41	—	—
Argentina	—	—	—	—	—	—	7
Australia	—	500	500	—	—	—	—
Brazil	2,300	4,900	4,900	108	89	(⁴)	7
Canada	—	1,100	1,100	—	—	—	—
Chile	—	—	—	—	1	—	—
China	NA	NA	NA	13	72	2	—
Cuba	700	700	2,000	14	—	—	—
Czechoslovakia	—	—	—	—	13	—	—
Egypt	NA	NA	NA	1	—	—	—
Finland	8,900	8,900	8,900	211	105	—	—
France	—	—	—	—	24	2	—
Germany, Federal Republic of	—	—	—	—	42	1	35
Greece	400	400	800	21	19	—	—
Greenland	—	—	26,000	—	—	—	—
Hungary	—	—	—	—	—	—	2
India	18,100	23,800	23,800	241	167	(⁴)	5
Indonesia	200	200	200	20	—	—	—
Iran	700	700	17,700	15	—	—	—
Italy	—	—	—	—	64	—	—
Japan	(⁵)	100	100	3	218	5	23
Korea	—	—	—	—	—	—	4
Madagascar	2,100	2,100	2,100	45	—	—	—
Mexico	—	—	—	—	4	—	5
New Caledonia	—	NA	NA	(⁴)	—	—	—
Norway	—	—	—	—	88	—	—
Oman	NA	NA	NA	1	—	—	—
Pakistan	NA	NA	NA	2	—	—	1
Papua New Guinea	—	—	2,900	—	—	—	—
Philippines	2,300	2,300	2,300	60	49	—	—
Poland	—	—	—	—	35	—	5
Romania	—	—	—	—	24	—	4
South Africa, Republic of	295,200	1,704,400	2,973,700	1,505	791	—	5
Spain	—	—	—	—	9	—	6
Sudan	500	500	500	2	—	—	—
Sweden	—	—	—	—	100	—	—
Taiwan	—	—	—	—	9	—	—
Thailand	NA	NA	NA	(⁴)	—	—	—
Turkey	2,500	6,000	6,800	440	70	—	8
U.S.S.R.	39,600	39,600	40,600	1,100	223	6	52
United Kingdom	—	—	—	—	1	5	24
United States	—	3,100	35,000	—	83	4	58
Vietnam	NA	NA	NA	1	—	—	—

See footnotes at end of table.

TABLE 22—Continued

WORLD CHROMIUM RESOURCES¹ AND ANNUAL PRODUCTION CAPACITY OF CHROMITE ORE, FERROCHROMIUM, CHROMIUM METAL, AND CHROMIUM CHEMICALS IN 1990

(Thousand metric tons, contained chromium)

	Resources ²			Annual production capacity			
	Reserves	Reserve base ³	Identified resources	Ore	Ferrochromium	Metal	Chemicals
Yugoslavia	NA	NA	NA	3	58	—	5
Zimbabwe	43,500	285,400	285,400	169	136	—	—
Total ⁶	418,900	2,086,600	3,441,600	4,193	2,535	25	257

NA Not available.

¹World resources derived in consultation with the U.S. Geological Survey.²Data and total rounded to nearest 100,000 metric tons.³The reserve base includes demonstrated resources that are currently economic (reserves), marginally economic (marginal reserves), and some of those that are currently subeconomic (subeconomic resources).⁴Less than 1/2 unit.⁵Less than 50,000 metric tons.⁶Data may not add to totals shown because of independent rounding.

further information on domestic reserves, reserve base, and resources, see Geology-Resources section of this report.)

Albania.—Albania continued construction of a ferrochromium plant at Elbasan. The plant was planned to have a production capacity in the range of 40,000 to 60,000 tons per year from three furnaces. The first of three furnaces was to have been completed in 1990. Albania produces most of its electrical energy at hydroelectric power stations that have had their output limited by water supply shortages resulting from drought. Because ferrochromium production is electrical energy intensive, ferrochromium production capacity has been limited by electrical energy supply.

Australia.—Dragon Resources Ltd. continued to develop its Range Well chromite in a laterite deposit near Cue in Western Australia. The company reported favorable results from a feasibility study for producing high-chromium cast iron grinding balls from its chromite resource. The study was carried out in cooperation with Crooks Mitchell Peacock Stewart (WA) Pty. Ltd. by shipping ore to Geraldton, where it was smelted and cast.

Bolivia.—Bolivia accepted applications for concessions for mineral exploration in the Rincon del Tigre. This 240,000-hectare area has been reported to contain chromite resources.

Brazil.—Companhia Ferroligas do Amapá's Vila Nova Mine produced chromite in Amapá Territory. The Vila Nova

Mine estimated its inferred chromite reserves at 7 million tons. Chromite production capacity was 50,000 to 60,000 tons per year of beneficiated product. The company planned to increase beneficiation capacity to 120,000 tons per year when an expansion was justified by chromite demand. Open pit mining resulted in run-of-mine (ROM) ore that typically graded 35% to 44% Cr₂O₃ with a chromium-to-iron ratio of 1.7:1, while beneficiated product typically graded 50% Cr₂O₃ with a chromium-to-iron ratio in the range of 2.0:1 to 2.3:1. ROM ore was beneficiated at the mine site from which it was transported by truck to the Cupixi railroad station, then by train to Santana for export.

Cia. de Ferro Ligas da Bahia S.A. (FERBASA) planned to construct four hydroelectric powerplants. FERBASA planned to construct two of those hydroelectric powerplants on the San Francisco River in Bahia State. Each was planned to have a production capacity of 50 megawatts. The first of these plants was planned to be completed in 1993. FERBASA planned to finance this project through Federal Government financial institutions. Owing to reduced world demand relative to supply, FERBASA reduced production by about 20% (from about 110,000 tons to about 80,000 tons) in 1990.

Companhia Ferroligas do Amapá (CFA) completed construction of its ferrochromium smelter at Porto de Santana at a cost in the range of \$14 to \$16 million. CFA's 12-megavolt-ampere furnace has a ferrochromium production capacity

of 20,000 tons per year. Ferrochromium production would be interchangeable with ferromanganese and ferrosilicon production, with the choice of product determined by market conditions.

Anuário da Indústria Brasileira de Ferroligas (ABRAFE), the Brazilian ferroalloy producers association, reported 1990 production as follows: high-carbon ferrochromium, 73,105 tons; low-carbon ferrochromium, 10,684 tons; ferrochromium-silicon, 4,973 tons; and chromium metal, 37 tons. ABRAFE reported 1990 exports as follows: high-carbon ferrochromium, 16,143 tons; low-carbon ferrochromium, 345 tons; and ferrochromium-silicon and chromium metal, none.

Canada.—Canada studied the development potential of its chromium resources. Coleraine Mining Resources Inc. evaluated the resources of the Hall deposit in Quebec. The Hall deposit was found to contain 1.04 million tons of chromite ore reserves graded at 4.5% Cr₂O₃, of which 801,400 tons grading at 4.6% Cr₂O₃ was proven. Chromium-to-iron ratio of the chromite was found to be 2.6:1. The reserve was found to be exploitable by surface mining. The deposit remains open at depth, and the company planned to continue surveying to determine the deposit's lateral extent. Coleraine Mining also planned to conduct a feasibility study for the production of ferrochromium using low-cost hydroelectric energy from Québec.

Sherwood Metallurgical Corp. continued development of a low-carbon ferrochromium smelter in Vancouver, British Columbia. The plant was planned

to have an initial production capacity of 30,000 tons per year of low-carbon ferrochromium containing 60% to 65% chromium. Producing at full capacity, the plant was planned to annually consume 300,000 megawatt hours of energy, 61,000 tons of chromite ore, 12,500 tons of low-sulfur reductant, and 22,000 tons of low-lime silica sand. A construction site was selected at Bear Cove in Port Hardy. The proposed plant was relocated to the Port Hardy area after local opposition was encountered at Mill Bay and Namaimo. The Port Hardy Ferrochromium Assessment Review Panel was expected to decide on whether or not to permit plant construction in 1991. The plant was opposed by the local Kwakiutl Indian tribe, which claims the proposed plant site and was concerned about the effect of a plant on local fishing. Sherwood also considered locating a low-carbon ferrochromium plant in New Brunswick.

Ferrochrome Canada, a joint venture including Showa Denko (Japan), Mitsui (Japan), Companhia Auxiliar Empresa Mineração SA (Brazil), and Société Général du Financement (Canada), planned an 80,000-ton-per-year-capacity high-carbon ferrochromium plant for Bécancour, Québec. The project was indefinitely postponed owing to the low price of ferrochromium (resulting from increased supply) and to the reduced likelihood of sanctions against the Republic of South African produced ferrochromium (resulting from improved performance of the South African Government in abandoning its apartheid policy).

China.—China reported chromite production from 1949 through 1988.¹⁵

China reported construction of the Norbusa Mine in Shannan district of Tibet Autonomous Region. Tibet has produced about 500,000 tons of chromite since 1979. The mine was planned to come into production in 1995, with an annual chromite production capacity of about 50,000 tons. The Lhobsa deposit is near the Yarlung Zangbo River. The development cost was estimated to be \$12 million and was to be financed by earnings from the Dongfeng chromite mine. The Dongfeng Mine was planned to close owing to consumption of reserves. Chromite from the Norbusa Mine was planned to be smelted to ferrochromium locally, and the ore was to be processed by the Tibet Chemical Works and smelted by the Lhasa Power Bureau and the Tibet Electrical Machinery Plant.

About 1,000 tons of ferrochromium was produced.

China deemphasized ferrochromium export owing to raw material supply shortages. Conversion contracts wherein foreign companies supplied ore for conversion were not effected.

The Chinese Ferroalloy Association reported Chinese high-carbon ferrochromium production in 1989 to have been in the range of 80,000 to 90,000 tons; low-carbon ferrochromium production was about 50,000 tons. Ferrochromium exports were reported to have been 8,000 tons in 1987, 24,000 tons in 1988, and 20,000 tons in 1989. Japan and the United States were the largest recipients of Chinese ferrochromium.

European Community.—European ferrochromium producers requested the European Commission to investigate U.S.S.R. and Albanian high-carbon ferrochromium imports to determine whether or not the ferrochromium was being dumped in the European Community. The European Commission opened an investigation, which it planned to complete in 1991. In July, the Council of European Communities increased the amount of high-carbon (more than 6% carbon) ferrochromium from nonmember states permitted to enter duty free from 300,000 tons to 450,000 tons.

Finland.—Outokumpu Chrome Oy operated a new concentrator at the Kemi Mine and a new pelletizing and sintering plant at its ferrochromium plant at Tornio. Construction of the new production facilities was completed in 1989, and these facilities were being brought up to full operating capacity, raising Outokumpu's sintered pellet production capacity to 300,000 tons per year and its ferrochromium production capacity to about 200,000 tons per year. The old sintering plant was to be dismantled. Outokumpu reported that Outokumpu Chrome Oy operated as an independent company and was a wholly owned subsidiary of Outokumpu Oy. Outokumpu planned to transfer ownership of Outokumpu Chrome Oy to Outokumpu Steel Oy effective January 1991. Outokumpu reported 1990 production of 1.1 million tons of chromite ore excavated (up from 0.8 million tons in 1989), 157,000 tons of ferrochromium (down from 169,000 tons in 1989), and 226,000 tons of stainless steel slab (up from 192,000 tons in 1989).

Greece.—Hellenic Ferroalloys SA (HFA) restructured its debt, power cost,

and ownership. HFA renegotiated its power rate from 10.2 to 4.75 drachmas per kilowatt-hour, to become effective in 1991. Also to become effective in 1991 was the new ownership structure wherein HFA was to be owned primarily by the Greek Finance Ministry (55%) and the state-run Public Power Corp. (35%). The Greek Government expressed interest in selling publicly owned companies, such as HFA, to the private sector. Interest in HFA was reported. However, no specific offers were revealed. The Greek Government was interested in developing stainless steel production in Greece through the sale of HFA and a sister nickel-producing company.

The National Bank of Greece granted HFA exclusive rights to mine chromite deposits near Domokos in central Greece. HFA planned to start mining the 1 million ton reserve at the rate of about 50,000 tons per year.

India.—**National.**—The large amount of ferrochromium production capacity licensed in 1989 stimulated debate over the best way for India to exploit its chromium resources. Some proposed development of India's ferrochromium industry so that India could benefit from supplying a higher value added commodity (i.e., ferrochromium instead of chromite ore) on the world market. Others proposed to develop the chromite ore-producing industry, but not the ferrochromium industry, reasoning that the ferrochromium plants are not cost effective. (The purpose of development is to earn hard currency, which could then be used for other Indian needs. The cost in hard currency, it was thought, of constructing ferrochromium plants would more than offset the income gain.) Yet others proposed limiting chromite ore exports for a variety of reasons, including the following:

- (1) There was not adequate chromite ore production capacity in India to supply the ore required by licensed ferrochromium producers.
- (2) Limiting chromite ore export could stimulate development of the electrical energy consuming industry (i.e., ferrochromium production) in States with excess electrical energy. Unfortunately, chromite ore resources and excess electrical power were not found in the same States.
- (3) Limitation of chromite ore export from the major producing area (Orissa State) would stimulate industrial growth in that State.

Many motivations and constraints are shaping the development of the Indian chromium industry.

The Indian Government announced its chromite ore export policy for April 1, 1990, through March 31, 1993. The new policy prohibits the export of either lumpy chromite ore with Cr_2O_3 content greater than 38% or friable chromite ore with Cr_2O_3 content greater than 52% and silica content lower than 4%. The Steel and Mines Minister of India introduced a new minerals policy that reserves exploration and processing of chromite for the Government. The Orissa State Government sought to have the Indian Government ban export of chromite ore from the Orissa. Orissa State holds 97% of Indian chromite reserves and accounts for more than 90% of Indian chromite ore production. Such a ban would have reduced supplies to foreign consumers, reduced the likelihood of ferrochromium plant construction outside Orissa, and favored chromite ore and ferrochromium producers in Orissa State. Orissa Mining Corp. and OMC Alloys Ltd. are the State-owned enterprises currently producing chromite ore and ferrochromium. Tata Iron and Steel Co. is the major private producer of chromite ore and new ferrochromium producer in Orissa. Ferro Alloys Corp. Ltd. (FACOR) and Indian Development Corp. are private ferrochromium producers in Orissa State.

Chromite Ore.—FACOR continued development of the Lakshmi shaft at its Boula Mine. The company planned to complete the chromite ore haulage shaft in 1992.

Tata Iron and Steel Co. (TISCO) started production from its new beneficiation plant at Sukinda chromite mine. The plant cost about \$13 million¹⁶ and has an annual production capacity in the range of 70,000 to 80,000 tons of chromite ore graded at 48% Cr_2O_3 with a chromium-to-iron ratio of 2.7:1 and 20,000 to 30,000 tons of chromite ore graded at 52% to 54% Cr_2O_3 with chromium-to-iron ratio of 3.2:1. Product size is in the range of 150 to 200 mesh. Chromite feedstock to the plant is graded in the range of 20% to 30% Cr_2O_3 .

Ferrochromium.—India's consumption of chromium materials was estimated to include about 60,000 tons of high-carbon ferrochromium and 10,000 tons of low-carbon ferrochromium annually. India is

virtually self-sufficient in ferrochromium supply. India operates a unique mixture of privately and publicly owned ferrochromium smelters. Larger smelters were licensed by the State, while smaller smelters operated without license. Licensed smelters are required to produce for domestic use or for export. It has been estimated that there is about 50,000 tons of ferrochromium production capacity at small (unlicensed) plants. Licensed production capacity nears 600,000 tons per year. However, substantially less production capacity is installed, and even less is available owing to insufficient electrical power availability from the national grid. India experienced electrical power shortages in Andhra Pradesh and Karnataka States. Andhra Pradesh reduced electrical power supply by 30% to 40%.

FACOR installed a captive electrical power generating facility (including a fuel oil storage facility) at its ferrochromium plant at Shreeramnagar in Andhra Pradesh State. The electrical powerplant consisted of three 10.5-megawatt diesel-powered electrical generators. This captive power station is capable of supplying about 60% of FACOR's needs at Shreeramnagar. FACOR planned to install two 10.5-megawatt electrical generators at its charge-grade ferrochromium plant in Orissa State. FACOR added a vacuum oxygen decarburizing furnace of its own design and construction to its processing facilities to supply medium-carbon ferrochromium produced from high-carbon ferrochromium to India's steel industry.

Indian Charge Chrome Ltd. (ICCL), a subsidiary of Indian Metals and FACOR, started production operation of its 108-megawatt captive powerplant, briquetting plant, and ferrochromium smelter at Choudwar, Cuttack District, Orissa State. ICCL is an export-oriented unit with an annual production capacity of 62,500 tons. ICCL arranged for Tata Iron and Steel to supply chromite ore and to market its ferrochromium production.

Ispat Alloys Ltd. planned to construct a ferrochromium plant in Ohankale District of Orissa State, where chromite ore was readily available. Ispat Alloys planned to use a pelletizing process from Outokumpu Oy (Finland) and a 45-megavolt-ampere furnace from Demag (Germany) at the export-oriented plant. Ispat planned to complete construction of the plant in 1991.

OMC Alloys, a subsidiary of Orissa Mining Co. and a public-sector company,

experienced financial difficulties. OMC identified increasing electrical power rates and inflation as the major causes of its problems. Since the plant started producing ferrochromium, electrical power cost has increased from \$0.0139¹⁷ per kilowatt hour to \$0.0566¹⁸ per kilowatt-hour. The rising cost of production and declining price of ferrochromium has resulted in unprofitable operation for OMC. Rupee value dropped by 30% to 60% due to inflation. This inflation has increased the cost of the foreign component of OMC's debt. OMC planned to improve its position by increasing production from the current 70% of capacity to the range of 80% to 85% of capacity.

TISCO converted a ferromanganese furnace to ferrochromium and constructed an export-oriented ferrochromium plant. TISCO had Elkem (Norway) renovate a 9-megavolt-ampere ferromanganese furnace at its ferromanganese plant at Joda, Kendujhar District, Orissa State, to a 12-megavolt-ampere ferrochromium furnace with an annual production capacity of 20,000 tons.

Kolmak Chemicals planned to build a ferrochromium plant at Raigarh, Madhya Pradesh. The new ferrochromium producer, Standard Chrome, was planned to have an annual production capacity of 15,000 tons. TISCO was expected to supply chromite ore, handle export sales, and cofinance the new business.

Indonesia.—Aneka Tambang, Indonesia's state-owned mining company, developed a chromite mine near Wosu Port, Sulawesi Island. Commercial production started in 1990 and included chromite ore for metallurgical use and for foundry sand use. Aneka planned to ship the metallurgical-grade chromite ore to Japan and the foundry sand-grade chromite ore to Gebe Island for cast iron production. The metallurgical-grade chromite ore is graded about 41% Cr_2O_3 , 17% FeO , 18% Al_2O_3 , and 11% MgO , with a chromium-to-iron ratio in the range of 1:1 to 1.6:1. The foundry-sand grade chromite ore contained about 52% Cr_2O_3 .

Iran.—Following the end of the Iran-Iraq war in 1988, Iran has been developing its chromium industry. Chromite ore exports have increased since the end of the war.

Italy.—Italcromo purchased a site (the Stefana di Termoli, an industrial site used

to produce steel from 1972 to 1986) at a cost of \$5.4 million¹⁹ and planned to construct four furnaces. The first two were planned to be 24-megavolt-ampere furnaces for ferrochromium production (convertible to ferromanganese). The second two furnaces, planned for construction in 1994, were planned to be for silicomanganese production (convertible to ferrosilicon). The first furnace (planned to have been purchased from Demag in Germany) was to be brought into operation in the second quarter of 1991. It was noted that Italy consumed on the order of 160,000 to 170,000 tons of ferrochromium annually, an adequate level of demand to support a domestic plant. Italcromo planned to produce high-carbon ferrochromium from Albanian ore.

Japan.—Japan operated a two-part stockpiling program, Government and private. Japan's goal is to acquire a stockpile of chromium adequate to serve its needs for 60 days, of which 42 days was to be in the Government stockpile and 18 days was to be in the private stockpile. The Metal Mining Agency of Japan, under the supervision of the Ministry of International Trade and Industry, operated the Government stockpile, while Japan Rare Metals Association operated the private stockpile. As of March 1990, Japan had acquired a stockpile of chromium adequate to serve its needs for 35.3 days in the Government stockpile and 15.1 days in the private stockpile. Japan planned to increase its Government stockpile to 2.8 days of consumption, while increasing its private stockpile to 1.2 days.

Japan reported stainless steel production of 2,410,725 tons in 1990, a decline of 11% compared with that of 1989. Japan's ferroalloy industry produced about 324,327 tons of ferrochromium, a decline of 9.0% compared with that of 1989. Japan's ferrochromium production has ranged from 260,000 tons to 360,000 tons per year in the 1980-90 time period. Japan imported 441,672 tons of ferrochromium in 1990, while it exported 2,811 tons, giving imports a 58% market share. Japan imported 789,225 tons of chromite ore with which to produce chromium ferroalloys and imported 550 tons of chromium metal.

Japanese ferrochromium producers suffered as a result of excess supply of ferrochromium in 1990. The Japan Ferroalloy Association studied the possibility of making an antidumping complaint

against ferrochromium imports owing to the low price of that material relative to the cost of production in Japan.

Japanese stainless steel producers, NKK and Kawasaki Steel, reported implementing innovative production techniques. NKK started production of nickel-containing stainless steel at its Fukuyama works in September. NKK combined nickel and chromite ores with coke and blast furnace iron in a converter, then blew the mixture with oxygen and nitrogen to produce stainless steel. The stainless steel was then continuously cast. Kawasaki processed chromite ore in a kiln at its Mizushima works then supplied the chromium product to a converter at its Chiba works for the production of stainless steel. It was thought that stainless steel production by these blast furnace steel producers would increase competition and result in a lower priced and more competitive stainless steel product.

Korea, Republic of.—Korea reported 1990 ferrochromium imports of 67,162 tons, consumption of 69,363 tons, and ending stocks of 11,953 tons.

Madagascar.—Kraomita Malagasy (Kraoma) mined 192,857 tons of chromite ore from which it produced 62,540 tons of marketable concentrate in 1989. Madagascar exported 134,338 tons of chromite in 1989.

New Caledonia.—Chromical Ltd., the chromite ore mining company that operates the Tiebaghi Mine in New Caledonia, continued mining until July 1990, while it prospected to extend chromite ore reserves. New Caledonia reported mining about 11,031 tons of run-or-mine chromite ore from which it produced about 6,207 tons of marketable concentrate.

Norway.—Elkem AS (Norway) purchased the fixed assets of Norsk Ferrokrom AS effective July 1990 and named the operation Elkem Rana AS. The assets included a briquetting facility and two ferrochromium-producing electric furnaces. One electric furnace started production in September 1989. Elkem planned to start the second furnace in 1991. The briquetting facility had an annual production capacity of 300,000 to 400,000 tons of chromite ore furnace feed. The operating furnace had a capacity of 45 megavolt amperes and was operated at 40 megawatts to produce about 70,000 tons of high-carbon ferrochromium

annually. Thus, with both furnaces in operation, Elkem could produce with an annual capacity of about 140,000 tons. Elkem planned to construct a concentrator to recover chromium from slag. Chromium recovery from slag would permit smelting-process-chromium recovery in excess of 80%. Norwegian sanctions against the Republic of South Africa prohibit importation of South African chromite ore.

Oman.—Oman Mining Co. (state owned) has mined chromite ore from deposits near Wadi Rajmi and exported about 8,000 tons of chromite between 1985 and 1989. Oman has identified more than 600 chromite occurrences. Detailed analysis of 36 deposits yielded 1 million tons of chromite ore reserves. Oman continues to explore for chromite in the area of Rajmi-Fizh and the Farfar-Hilti areas of northern Oman.

Philippines.—Chromite Ore.—At the request of the Philippine Government, the Japan International Cooperation Agency is conducting a 3-year study of chromite resources on Palawan Island. The study is funded by the Metal Mining Agency (Japan) and was estimated to cost about \$2 million.

Merlin Mining Co. (Australia) acquired 24.4% interest in Acoje Mining Co., owner of the Acoje Mine in Zambales Province. Merlin also holds leases near the Acoje Mine, from which it produces chromite fines from alluvial deposits and owns leases on Dinagat Island. Acoje Mining Co. started mining in the late 1930's, from which time it has produced about 3 million tons of chromite ore. As a result of excessive debt and labor problems, production has declined to about 36,000 tons per year. Merlin planned to invest in the Acoje Mine to bring the mine's production up to about 100,000 tons per year. In situ reserves were estimated at 4 million tons.

The Philippine Government signed an agreement with Benguet Corp. to develop a refractory chromite mine from deposits owned by Consolidated Mines Inc.

The Philippine Government and the United Nations Revolving Fund for Natural Resources Exploration (UNRFNRE) agreed to develop chromite deposits on Dinagat Island. The deposit was estimated to contain in the range of 1 to 2 million tons of massive metallurgical-grade chromite ore graded at 50% Cr₂O₃.

Ferrochromium.—Ferrochrome Philippines Inc. operated a ferrochromium smelter with a production capacity of about 54,000 tons per year. Integrated Chrome Corp. operated a ferrochromium smelter with a production capacity of about 18,000 tons per year.

South Africa, Republic of.—Labor Relations.—The National Union of Metalworkers of South Africa (NUMSA) represents ferrochromium workers at Consolidated Metallurgical Industries, Ferrometals, Feralloys, Middelburg Steel and Alloys, and Tubatse. Contracts were renegotiated without work interruptions at Consolidated Metallurgical Industries, Feralloys, Middelburg Steel and Alloys, and Tubatse. Ferrometals experienced a strike during part of August and September before a new contract was agreed upon. Issues included job security and pay rates.

Chromite Ore.—High demand for chromium in 1989 resulted in the creation of new, independent chromite ore mining operations in the Republic of South Africa that utilize surface mining methods. As a result, the new operations can produce chromite ore at a cost less than that of established underground operations. The cost difference is expected to last until surface minable reserves are exhausted. Established South African chromite ore producers reported that wage increases, inflation, and rail transportation cost increases contributed to the increased cost of chromite ore. South Africa's Minerals Bureau reported 1989 chromite ore production (excluding Bophuthatswana) at 4,274,700 tons, an increase of 13% over that of 1988 and a record high for the second year in a row. The Minerals Bureau reported 1989 sales to have been as follows: domestic, 2,542,000 tons (up 19% over that of 1988); and foreign, 1,371,000 tons (up 3.5% over that of 1988). Domestic sales set a record high, exceeding the previous high in 1987 by 17.8%.

Lebowa Development Corp, owner of the Dilokong Chrome Mine in Lebowa, reported mine developments raising annual production capacity to 300,000 tons effective in 1990. The production composition was to include 69,000 tons of lumpy chromite ore, 58,000 tons of small lumpy ore, and 173,000 tons of fine chromite ore.

Hernic Pty. Ltd. started production late in 1989 from reserves of about 3.052

million tons and reached full potential in 1990. Ore reserves include 1.743 million tons in the GM-1 seam (primarily metallurgical grade) and 1.309 million tons in the GM-2 seam (primarily chemical and refractory grades). Open pit mining yields a range of 30,000 to 40,000 tons of chromite ore per month after removal of 25 meters of overburden and with an eventual change to underground mining when production capacity will shift to a range of 20,000 to 30,000 tons of chromite per month. A beneficiation plant under construction, at a cost of \$1.7 million,²⁰ was planned to produce 12,000 tons of lumpy chromite ore per month and 18,000 tons of chromite concentrate per month. A captive loading facility, under construction at Marikana station (11 kilometers from the mine), was to have a loading capacity in the range of 15,000 to 20,000 tons of chromite ore per month when completed in 1990. (Wolhuterskop station, 25 kilometers from the mine, was to be used until the Marikana facilities were completed.) Typical chromite ore specification were as follows: lumpy, 39.5% Cr_2O_3 , chromium-to-iron ratio of 1.50:1; chemical grade, 46.54% Cr_2O_3 , chromium-to-iron ratio of 1.55:1; concentrate, 45.0% Cr_2O_3 , chromium-to-iron ratio of 1.51:1. Hernic's mine is south of Samancor's Mooiooi Mine in the Rustenburg district, Transvaal Province (western belt of the Bushveld Complex). Beneficiation includes crushing, screening, and spiral classifiers.

Goudini Mine started open pit production of chromite ore early in 1990, with reserves in the range of 70 to 75 million tons. Goudini Mine is in the western belt of the Bushveld Complex. Ore has an unusually high chromium-to-iron ratio of 2:1, with lumpy ore grading 40% Cr_2O_3 and concentrate, above 50% Cr_2O_3 . Production was reported at the rate of about 80,000 tons per year in 1990, with a target production capacity of 200,000 tons per year.

Elandsdrift Chrome (Pty.) Ltd. was organized in September 1989 and started opencast mining in June 1990. The beneficiation plant was completed in February 1990. Chromite ore was mined from an inferred reserve of 1.5 million tons in the MG-1 seam. Run-of-mine ore grading 44% Cr_2O_3 was about 30% lump and 70% fines. The beneficiation plant, including a rod mill and spiral separators, produced about 9,000 tons per month, with expansion to 18,000 tons per

month planned. Shipping was by rail from the nearby Marikana station.

A new process, recovery of platinum-group metals from chromite ore tailings, was being implemented. Temex, the mining exploration division of Genwest Group, erected a plant in western Transvaal Province. In addition to platinum-group metals, the new plant was to produce chromite concentrate.

Ferrochromium.—The Republic of South Africa's Minerals Bureau reported 1989 ferrochromium production at 993,920 tons, an increase of only 0.02% over that of 1988 and a record high for the third consecutive year. The Minerals Bureau reported 1989 sales to have been as follows: domestic, 59,552 tons (up 2.4% over that of 1988 and a record high); and foreign, 930,571 (down 3.6% over the record high of 1988).

Chromecorp Technology (CCT) operated the two electric arc furnaces (electrical capacity, 30 megavolt amperes and production capacity, 50,000 to 60,000 tons per year each), while it completed construction in April 1990 of a third furnace like the first two. With completion of its third furnace, CCT had a production capacity in the range of 150,000 to 180,000 tons per year. CCT also operated a captive chromite mine, the Chromobronne Mine.

Consolidated Metallurgical Industries Ltd. (CMI), a subsidiary of Johannesburg Consolidated Investment Co. Ltd., started its third 32.5-megavolt-ampere furnace at its plant near Lydenburg, Transvaal Province. The additional furnace increased CMI's production capacity from a range of 150,000 to 160,000 tons per year to a range of 200,000 to 210,000 tons per year. CMI purchased the issued share capital of Purity Chrome Pty. Ltd. (a chromite ore mining and beneficiating company) and the assets of Purity Ferrochrome Pty. Ltd. (a ferrochromium producer) for \$49 million.²¹ At the time of purchase, Purity Chrome Mine had a production capacity of about 250,000 tons per year of chromite ore with chromium-to-iron ratio of 1.55:1. Chromite ore production included lumpy, grading 40% to 42% Cr_2O_3 , and fines, grading 45% Cr_2O_3 . Purity Ferrochrome included two electric arc furnaces of 33-megavolt-ampere power capacity and 120,000 tons per year charge-grade high-carbon ferrochromium production capacity. With this purchase, CMI acquired a captive chromite mine and additional

ferrochromium production capacity, yielding a total capacity in the range of 320,000 to 330,000 tons per year for CMI and Purity combined.

Middelburg Steel and Alloys (Pty.) Ltd. reorganized itself into MS&A Chromium (Pty.) Ltd. (MS&A), responsible for the chromium ferroalloy production and marketing, and MS&A Stainless (Pty.) Ltd., responsible for stainless steel production and marketing. Middelburg Steel and Alloys (Pty.) Ltd. retains responsibility for the new companies' strategic planning. MS&A completed construction of a rotary kiln and electric arc furnace for application of the chrome direct reduction (CDR) process that MS&A developed with Krupp (Germany). The project will add 120,000 tons per year of ferrochromium production capacity during a 3-year period, while the new equipment and process is being brought to full capacity operation at a cost to MS&A of about \$97 million.²² The new process offers several cost-reducing features, including the following: (1) The CDR process uses chromite ore fines that are available at lower cost than chromite ore lumps, and (2) the CDR process uses coal as a source of energy for reducing a substantial fraction of the chromite ore before the partially reduced product is fed into an electric arc furnace for completion of the reduction process. Energy supplied from coal is less expensive than energy supplied from electricity.

Tubatse started production from its fifth furnace in February 1990. Tubatse started producing ferrochromium with three furnaces, each with electrical transformer capacity of 30 megavolt-amperes and production capacity of about 50,000 tons per year. Tubatse modified its furnaces, changing production capacity to about 60,000 tons per year for each furnace. Tubatse then added two furnaces, each with electrical transformer capacity of 37 megavolt-amperes and production capacity of about 60,000 tons per year. The fourth furnace was brought into production in 1989. Tubatse now has a production capacity of 300,000 tons per year.

South Africa Manganese Amcor Ltd. reported its analysis of the world chromium growth prospects. Samancor estimated world stainless steel production to have grown historically at a rate of 2.4%. At this growth rate, Samancor estimated the world chromium industry would be required to add about 100,000 tons of fer-

rochromium production capacity and about 300,000 tons of stainless steel production capacity annually. The Republic of South Africa was estimated to produce only about 1% of world stainless steel production. Samancor found these conditions encouraging to the development of stainless steel production capacity in the Republic of South Africa. Samancor and Highveld Steel & Vanadium planned a 300,000-ton-per-year capacity stainless steel plant. It was suggested that such a plant could be built at Witbank within a 3-year period. Expanded stainless steel production would be the next step in vertically integrating and expanding the Republic of South Africa's chromium industry.

Purity Ferrochrome, a subsidiary of Consolidated Metallurgical Industries Ltd., brought its first furnace into operation in June and its second in July 1990. Each furnace is of Tanabe Kakoki (Japan) design and has electrical capacity in the range of 30 to 33 megavolt-amperes and production capacity of about 60,000 tons per year. (See Consolidated Metallurgical Industries Ltd. on previous page.)

Spain.—Empresa Nacional Adaro de Investigaciones Mineras S.A. (ENADIMSA), a state-owned Spanish company, in cooperation with the University of Madrid, reported the results of minerals exploration on the northwest coast of Spain. The exploration geologists targeted chromite because the Cape Ortegal Complex is composed of rock types known to be associated with chromite. The geologists found clear indicators of chromium mineralization in northwestern Spain. The mineral rights of the area are covered by ENADIMSA claims.

Sweden.—SwedeChrome AB closed its ferrochromium plant at Malm in January 1990. The plant was closed because of the declining price of ferrochromium, an unfavorable cost position due to the Swedish embargo toward South African chromite, and, to a lesser degree, uncertainty about electrical power rates. With SwedeChrome out of production, Sweden was left with one ferrochromium producer, Vargn Alloys AB. Vargn produces high-carbon ferrochromium with an annual capacity of about 160,000 tons.

Turkey.—Mine and smelter development was planned by Egemetel Madencilik AS in cooperation with three Korean

companies, Yukong Ltd., Sunkyoung Ltd., and Korea Mining Promotion Corp. Mine development was planned to start in 1990 followed by smelter development in 1991, with completion in 1993 at a cost of \$34 million. The ferrochromium smelter was planned to have a production capacity of about 40,000 tons per year, of which 20,000 tons was planned to be supplied to Korea to meet about 20% of Korea's ferrochromium demand. The smelter was planned to be at the mine site in Bursa Province.

Etibank, Turkey's Government-owned company that owns chromite mines and the only ferrochromium smelters in Turkey, completed construction of two new furnaces in 1989, when one of those furnaces was brought into production. The second new furnace started trial operation in 1990. When both new furnaces are operating at full capacity, Etibank will have a high-carbon ferrochromium production capacity of 150,000 tons per year. Etibank considered reorganizing its sales operation in the United States. Etibank has sold its ferrochromium product quarterly on a tender basis to U.S. merchants, who then sell the material to consumers. Etibank may enter a joint-venture arrangement to create an exclusive agent company for Etibank's ferrochromium in the United States.

U.S.S.R.—Donskoy Ore Dressing Complex is at Khromtau city, about 90 kilometers east of Aktyubinsk, Kazakhstan Republic. Ore was discovered there in 1936. The complex operated with a work force of 5,000 compared with a local population in Khromtau city of 25,000. Proven ore reserves were reported to have been 300 million tons at 43% to 44% Cr₂O₃; total ore reserves (including inferred), 1,000 million tons. Production was planned to increase to 4 million tons per year by the year 2000. Run-of-mine chromite ore was mined and then screened into lumps and fines. Tailings (material in the size range of 0 to 3 millimeters and containing 40% Cr₂O₃) were stockpiled and amounted to about 5.0 million tons by yearend. Upgrading tailings for export was planned.

Donskoy Ore Dressing Complex planned to expand its beneficiation facilities. The new beneficiation facility was planned to have a production capacity of 400,000 tons per year. Construction was planned to be completed in 1993, and shipments were planned to start in 1994. This additional production capacity

would increase the operation's production capacity from 3.6 to 4.0 million tons per year. The new beneficiation facility has been designed to utilize ore grades of 37% to 38% Cr₂O₃.

United Kingdom.—Metal Alloys Ltd. of South Wales ceased production of chromium metal when the company was sold, and its new owner elected to discontinue chromium metal production. United Kingdom is left with two chromium metal producers, London & Scandinavian Metallurgical Co. Ltd. and Murex—a division of SKW Metals UK Ltd.

Vietnam.—Vietnam operated the Nui Nua chromite mine in Than Hoa Province. Chromite was discovered there in 1927, and mining started in 1930. Production was about 8,000 tons per year until 1960. Production peaked at 36,000 tons in 1963, then dropped in 1980 to the range of 3,500 to 4,000 tons per year. Mining is from an alluvial deposit in which about 70% of the ore is in the size range of 0.07 to 0.28 millimeters. The chromite has a Cr₂O₃ content in the range of 47.3% to 51.5% and Al₂O₃ content of about 12%. Vietnam planned to replace current water-jet mining with modern dredging. There is an oversupply of modern tin dredges in Southeast Asia.

Zimbabwe.—The Government of Zimbabwe, Union Carbide (owner of Zimbabwe Mining and Smelting), and Zimbabwe Alloys are developing technology to mechanize the recovery of chromite from the narrow seams in the Mutorashanga area of the North Dyke. The objective is to make chromite recovery economic, thereby creating an estimated 500 million tons of chromite reserves for the country. The group will acquire and operate an Atlas Copco-Eikhoff (Federal Republic of Germany) roadheader on a narrow North Dyke chromite seam to test the feasibility of using such technology. The group planned to study a mechanized low-profile rock cutter for efficient stoping operations. Owing to a lack of economic recovery methods for narrow seam chromite mining, many northern Great Dyke mines are unmechanized and operated by cooperatives. Zimbabwe reviewed its chromium mining industry, reporting mine locations, cumulative production, and time period of operation.²³

TABLE 23
CHROMITE: WORLD PRODUCTION, BY COUNTRY¹

(Metric tons, gross weight)

Country ²	1986	1987	1988	1989	1990 ^e
Albania ^c	850,000	830,000	750,000	^r 610,000	600,000
Brazil ³	^r 353,000	^r 337,500	^r 410,256	^r 475,949	476,000
China	50,000	32,000	26,000	^e 25,000	25,000
Cuba	50,000	52,400	^r 52,200	^r 50,600	50,000
Finland ⁴	678,091	543,000	^e 700,000	^r 498,000	500,000
Greece ⁵	^r 60,063	63,825	^r 49,535	^r 56,000	60,000
India ⁶	^r 629,671	623,591	^r 820,863	^r 1,002,659	995,000
Indonesia	—	—	7,636	^r 7,635	8,000
Iran	^r 54,000	^r 55,000	^r 57,000	^r 62,000	60,000
Japan	10,642	11,815	9,508	^r 11,674	7,800
Madagascar	82,910	106,600	^r 64,177	^r 62,540	62,000
New Caledonia	72,207	61,832	70,341	^r 60,281	^r 6,207
Oman	4,820	—	—	—	—
Pakistan	8,299	^r 10,181	3,327	^r 27,105	20,000
Philippines	174,230	187,900	^e 190,000	^r 173,200	197,950
South Africa, Republic of ⁸	3,907,000	^r 3,789,000	4,245,000	^r 4,950,854	^r 4,497,700
Sudan	8,500	13,015	8,000	^r 25,000	15,000
Thailand	361	5	776	^r 416	500
Turkey ⁴	^r 617,652	^r 762,071	^r 851,425	^r 1,000,000	850,000
U.S.S.R.	3,640,000	3,570,000	3,700,000	3,800,000	3,800,000
Vietnam ^e	4,000	4,000	4,000	^r 3,500	3,500
Yugoslavia	8,780	13,172	11,538	^e 12,000	11,000
Zimbabwe	533,105	570,298	561,477	^r 627,424	600,000
Total	^r 11,797,331	^r 11,637,205	^r 12,593,059	^r 13,541,837	12,845,657

^cEstimated. ^rRevised.

¹Table includes data available through May 7, 1991.

²In addition to the countries listed, Bulgaria and North Korea may also produce chromite, but output is not reported quantitatively, and available general information is inadequate for formulation of reliable estimates of output levels. Figures for all countries represent marketable output unless otherwise noted.

³Average Cr₂O₃ content is as follows: 1986—40.0%, 1987—40.0%, 1988—39.0%, 1989—39.5%, 1990—not available. Brazil also reports run-of-mine crude ore production (and Cr₂O₃ content) in metric tons as follows: 1986—762,599 (173,068); 1987—829,739 (172,215); 1988—779,258 (208,812); 1989—90—not available.

⁴Direct-shipping lump ore plus concentrate and foundry sand.

⁵Exports of direct-shipping ore plus production of concentrates.

⁶India production for 1985 was, in metric tons, 569,475 (revised).

⁷Reported figure.

⁸Includes production by Bophuthatswana, which was as follows, in metric tons: 1986—451,900 (revised); 1987—522,900 (revised); 1988—536,500; 1989—676,154; and 1990—550,000 (estimated).

Current Research

U.S. Bureau of Mines research provides fundamental scientific and technical information essential for advancing mineral science, processing technology, and conserving and developing domestic mineral resources. This research is conducted in support of the Strategic and Critical Materials Stock Piling Act of 1946 as amended, the Defense Production Act of 1950 as amended, the Mining and Minerals Policy Act of 1970, and the National Materials and Minerals

Policy, Research and Development Act of 1980. Recent research related to chromium includes the study of chromite recovery from domestic deposits, the development of analytic techniques to study chromium alloys, and the recovery of chromium from waste.

The Bureau studied chromite recovery from California ores using physical concentration processes. Ore from three previously producing deposits was beneficiated in laboratory and pilot plant scale studies. Laboratory beneficiation

studies included tabling, vanning, spiraling, Reichert tray concentration, and froth flotation. The results of the laboratory studies were used to design the pilot scale studies. Pilot scale overall recovery ranged from 66% to 91% concentrating chromite ore with Cr_2O_3 content in the range of 11% to 15% to a chromite ore concentrate with Cr_2O_3 content exceeding 50% Cr_2O_3 and a chromium-to-iron ratio of greater than 2:1.²⁴

The Bureau, as a result of numerous chromite ore and ferrochromium analyses, has developed analytical methods that are reliable yet rapid. The Bureau documented those procedures, materials, and supplies used to analyze for chromium.²⁵

The Bureau found that traditional etching methods did not yield stains satisfactory for accurate image processing system (IPS) analysis of chromium carbide volume fraction of high-chromium white cast irons. A successful etch procedure was developed by optimizing etching parameters of composition, temperature, and time to yield carbide contrast satisfactory for IPS analysis.²⁶

The Bureau studied the recovery of chromium from hardface alloy grinding waste and contaminated superalloy scrap. Researchers developed a hydrometallurgical process that recovers chromium in the form of chromic chloride solution from hardface alloy grinding waste and economically evaluated the process. About 79% of chromium contained in the hardface alloy grinding waste was recovered as commercial-grade chromic chloride. Economic evaluation resulted in estimated capital cost of \$4 million and operating cost of \$11.70 per kilogram of feedstock for a plant processing 200,000 kilograms per year.²⁷ The Bureau also developed a process for the recovery of chromium as a filterable precipitate from superalloy scrap. The mixed and contaminated superalloy scrap was first pyrometallurgically treated to produce a feed material for hydrometallurgical processing that produced the chromium as filterable precipitate ferroalloy.²⁸ In addition, Bureau researchers developed a process to recover chromium primarily in the form of insoluble chromium carbide anode sludge from mixed and contaminated superalloy scrap. The superalloy scrap is melt carburized to produce an anode containing the chromium carbide.²⁹

The Council for Mineral Technology (MINTEK) of the Republic of South

Africa developed chromite ore and ferrochromium reference materials. The reference materials are produced by crushing, milling, and blending bulk samples and are distributed.³⁰

Private industry researched more economic production and utilization processes. For example, private industry developed the hollow electrode system for use in the ferrochromium production process and applied it to chromite ore fines. The process was compared with other techniques for efficient fine-chromite ore consumption. In particular, the hollow electrode system was found to be a potential substitute for cost-intensive briquetting, pelletizing, or sintering processes.³¹ Private industry implemented a chromium-aluminum hazardous waste recycling process. Chromium conversion chemicals are used in the aluminum metal finishing process generating a chromium-aluminum containing hazardous waste (EPA designation F019). The waste contains chromium hydroxide precipitate. About 15,000 tons of this waste, containing 3% to 15% chromium, has been generated annually. EPA permits the waste to be land filled after the contained chromium has been immobilized or fixed. However, the industry process recovers chromium from the material by first dissolving it, then precipitating chromium hydroxide, which is calcined to produce a material containing 50% to 55% chromic oxide.³²

OUTLOOK

On the average in the United States, about 70% of chromium is consumed by the metallurgical industry, and about 70% of metallurgical industry chromium consumption is for stainless steel production. Stainless steel, by definition, contains at least 11% chromium but may contain up to 36% chromium. Thus, stainless steel production accounts for about one-half of the chromium consumed in the United States. The remainder is consumed in the production of other ferrous and nonferrous alloys, chemicals, and refractories. Some of the chemical and refractory products are consumed in the steel production process.

On the average internationally, about 79% of chromium is consumed by the metallurgical industry, 13% by the chemical industry, and 8% by the refractory

industry. Of the chromium consumed in the metallurgical industry, about 60% is consumed in stainless steel. Thus, stainless steel production accounts for about one-half of the chromium consumed internationally.³³

The outlook for chromium consumption in the United States and internationally is the same as that for stainless steel. Stainless steel is estimated to be the major end use for chromium worldwide. Thus, stainless steel industry performance determines chromium industry demand worldwide.

The trend to supply chromium in the form of ferrochromium by chromite mining countries is expected to continue. The rate at which new ferrochromium plants come into production is expected to diminish now that all major chromite producers have such facilities. With new, efficient ferrochromium production facilities and excess capacity in chromite-producing countries, both production and capacity are expected to diminish in traditional ferrochromium-producing countries, except where domestic industries are protected by quotas and tariffs. Further upward integration of the chromium industry is expected as chromite-producing countries expand current capacity or develop new stainless steel production capacity.

A review of cement kiln refractories found that mag-chrome (magnesia-chromite) refractories are used in the transition zones of cement kilns because chromite is inexpensive, provides resistance to acidic slags, and moderates thermal expansion that leads to excessive spalling. U.S. specific consumption of mag-chrome refractories was estimated to average about 0.31 kilograms per metric ton of clinker product. EPA regulation of used chromium-containing refractories (see Legislation and Government Programs section) was expected to increase the life-cycle cost of those refractories by increasing disposal cost. Increased disposal cost was expected to result in substitution of magnesia-spinel refractories for the mag-chrome refractories currently used.³⁴

The world chromium markets were reviewed and classified as follows: structural and utilitarian stainless steels, stainless and heat-resisting steels, other metals and alloys, alloy steels, foundry sand, chemicals, and refractories. These markets were categorized as being growth or mature markets. (A mature market is a

TABLE 24
CHROMIUM SUPPLY-DEMAND RELATIONSHIPS

(Thousand metric tons, contained chromium)

	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
WORLD PRODUCTION												
Chromite ore (mine) ¹	2,807	2,981	2,736	2,553	2,472	2,943	3,295	3,497	3,450	3,730	3,993	3,784
Ferrochromium (smelter) ²	1,707	1,632	1,510	1,314	1,354	1,613	1,695	1,689	1,794	1,866	1,874	NA
Stainless steel, Western World ³	NA	1,171	1,084	1,049	1,185	1,364	1,343	1,343	1,561	1,788	1,734	NA
U.S. SUPPLY												
Components of U.S. supply:												
Domestic mines	—	—	—	—	—	—	—	—	—	—	—	—
Secondary	64	58	65	61	75	79	85	84	95	119	99	94
Imports:												
Chromite ore	258	254	228	130	53	83	109	133	133	185	162	92
Chromium ferroalloy	123	160	228	79	148	223	173	206	171	255	208	244
Chromium metal	3	4	3	2	3	4	4	4	4	4	4	7
Chromium chemicals	(⁴)	1	1	2	4	3	5	4	3	2	5	4
Chromium pigments	2	3	2	1	2	2	2	2	2	4	NA	NA
Stocks, Jan. 1:												
Government	1,301	⁵ 1,051	1,051	1,051	1,051	1,051	1,051	⁶ 1,080	⁶ 1,110	⁶ 1,079	⁶ 1,057	⁶ 1,097
Industry	399	288	219	232	181	164	114	106	102	119	137	139
Total U.S. supply	<u>2,152</u>	<u>1,818</u>	<u>1,798</u>	<u>1,558</u>	<u>1,518</u>	<u>1,609</u>	<u>1,542</u>	<u>1,619</u>	<u>1,620</u>	<u>1,767</u>	<u>1,673</u>	<u>1,676</u>
Distribution of U.S. supply:												
Exports:												
Chromite ore	4	2	18	2	3	15	27	25	(⁴)	1	12	2
Chromium ferroalloy	8	16	7	3	2	9	6	3	2	5	6	5
Chromium metal	(⁴)	(⁴)	(⁴)	(⁴)	(⁴)	(⁴)	(⁴)	(⁴)	(⁴)	(⁴)	(⁴)	(⁴)
Chromium chemicals	9	9	6	5	5	7	4	7	6	8	6	7
Stocks, Dec. 31:												
Government	1,301	1,051	1,051	1,051	1,051	1,051	1,080	1,110	1,079	1,057	1,097	1,099
Industry	288	219	232	181	164	114	106	102	119	137	139	118
Total U.S. distribution	<u>1,610</u>	<u>1,297</u>	<u>1,314</u>	<u>1,243</u>	<u>1,226</u>	<u>1,197</u>	<u>1,223</u>	<u>1,247</u>	<u>1,207</u>	<u>1,208</u>	[†] 1,260	1,231
Apparent industry demand	542	521	483	315	292	412	349	402	382	537	[†] 452	447

[†]Revised. NA Not available.

¹Calculated assuming chromite ore to average 44% Cr₂O₃ that is 62.48% chromium.

²Calculated assuming chromium content of ferrochromium to average 57%.

³Calculated from World Stainless Steel Statistics, 1990 ed. reported production, assuming chromium content of stainless steel to average 17%.

⁴Less than 1/2 unit.

⁵Nonstockpile-grade material that was included before 1980 was deleted from stockpile count.

⁶Variation in stockpile quantity does not contribute to apparent industry demand because variation results from upgrading programs.

market whose growth rate is less than that of gross national product. Similarly, a growth market is a market whose growth rate is greater than that of gross national product.) Growth markets for chromium were found to be structural and utilitarian stainless steels, stainless and heat-resisting steels, and other metals and alloys. The remaining markets were found to be mature. Each of the growth markets was described.³⁵

A review of the refractory and ceramic industries in the United Kingdom found that chromite ore has suffered a marked decline since 1950, when 150,000 tons was used. Chromite refractories are used primarily in steel production, but also in cement and glass production. This decline was found to be consistent with a general trend in the steel and cement-producing industries toward smaller unit consumption of refractories

(i.e., refractory consumption per unit of product). In addition to smaller unit consumption of refractories, these industries have experienced reduced growth rates in relation to gross national product. In particular, plastics have substituted for steel in automobiles and for glass in bottles.³⁶ A review of the foundry casting industry found the role of chromite to be particularly useful in sand casting of large castings for chilling rather than finish. It was

noted that in Europe, chromite has found a role as substitute material for zircon, the traditional material. Lack of suitable zircon has resulted in greater use of zircon-chromite blends or chromite alone in greensand casting.³⁷

The world chromium metal market was reviewed and found to be a highly competitive market in which consumption and production are in near balance and production capacity far exceeds production. World production was estimated at 15,000 tons (13,500 Western World, 1,500 China and U.S.S.R.), of which about 70% was produced by the aluminothermic process and the remaining 30% by the electrolytic process. Japan was identified as the source of 37% of world production, leaving 53% for the remainder of the Western World. Consumption, however, was concentrated in the Americas (52%), Western Europe (31%), and Japan (13%). The end-use market for chromium metal was primarily superalloys (44%), aluminum alloys (16%), and welding and hard-facing materials (15%), followed by corrosion resistant alloys (9%), electrical wire (8%), and miscellaneous uses (8%). Chromium metal consumption prospects were optimistic. While there did not appear to be preeminent new uses, there also did not appear to be replacements in the traditional end user market, jet engines. In the United Kingdom, consumption prospects were optimistic because vacuum induction melting (the production route by which chromium metal is used to make superalloy castings) capacity was expected to increase. A significant change in the chromium metal industry has been the recent introduction of upgraded aluminothermic chromium metal, which now accounts for 5% of the world market. The price of high-grade electrolytic chromium metal has lead the price structure for chromium metal. The impact of this new upgraded aluminothermic chromium metal has been to reduce the high end price of chromium metal. The price of low-graded chromium metal has been pressured further downward by Chinese and Soviet produced material.³⁸

Johan, M. Economou, and T. Engin (eds.). *Chromites*, Unesco's IGCP-197 Project Metallogeny of Ophiolites (Chromite Deposits and Occurrences). Theophrastus Publ. S.A., Athens, Greece, 1986, 339 pp.

³Papp, J. F. Chromium. Ch. in *Minerals Facts and Problems*, 1985 ed. BuMines 675, 1985, pp. 142-145.

⁴Because chromium ore price changes may lag those of ferrochromium by only a few months, the tables may show peak average annual values occurring in the same year.

⁵Boyle, E. H., D. J. Shields, and L. A. Wagner. Chromium Availability and Supply. BuMines information circular in progress.

⁶Burrows, D. Chromium: Metabolism and Toxicity. CRC Press, 1983, 184 pp.

Health Effects Assessment for Trivalent Chromium. Environmental Protection Agency, Report EPA/540/1-86-035, Sept. 1984, 32 pp.

Health Effects Assessment for Hexavalent Chromium. Environmental Protection Agency, Report EPA/540/1-86-019, Sept. 1984, 49 pp.

⁷Federal Register, V. 55, No. 123, June 26, 1990, p. 25993.

⁸_____. V. 55, No. 15, Jan. 23, 1990, p. 2322.

⁹U.S. Environmental Protection Agency. Report to Congress on Special Uastes From Mineral Processing. Volume I: Summary and Recommendations. July 1990, pp. 2, 11-12.

¹⁰Federal Register. V. 55, No. 106, June 1, 1990, pp. 22563-22565.

¹¹Public Law 101-549, Nov. 15, 1990.

The Hazardous Waste Consultant. The Clean Air Act of 1990—A Detailed Analysis. V. 9, Issue 1, pp. 4.1-4.30, Jan.-Feb. 1991.

¹²Chromium. 25 Minutes. Presented in cooperation with American Chrome & Chemicals Inc. For additional information, contact Audiovisual Programs, Office of Public Information, U.S. Bureau of Mines, Washington, DC 20241.

¹³Kessel, K. A. Strategic Minerals: U.S. Alternatives. Natl. Defense Univ. Press, 1990, 293 pp.

¹⁴Weber, L., and I. Pleschitschnig. World Mining Data Series B Volume I Chromit. Bundesministerium fur wirtschaftliche Angelegenheiten, Oberste Bergbehörde, Roh- und Grundstoffe, Landstraßer Hauptstr. 55-57 A-1032 Wien, Germany, 1990, 179 pp.

¹⁵The Yearbook of Iron and Steel Industry of China (1989). The Editorial Board of the Yearbook of Iron and Steel Industry of China. Metall. Ind. Press, Oct. 1989, v. 1, p. 197.

¹⁶Value has been converted from Indian Rupees (Rs) to U.S. dollars (US\$) at the rate of Rs1.00=US\$0.0578 (Rs17.3=US\$1.00).

¹⁷Value has been converted from Indian Rupees (Rs) to U.S. dollars (US\$) at the rate of Rs1.00=US\$0.0578 (Rs17.3=US\$1.00).

¹⁸Value has been converted from Indian Rupees (Rs) to U.S. dollars (US\$) at the rate of Rs1.00=US\$0.0578 (Rs17.3=US\$1.00).

¹⁹Value has been converted from Italian Lire (L) to US dollars (US\$) at the rate of L1.00=US\$0.0008347 (L1,198 US\$1.00).

²⁰Value has been converted from South African Rand (R) to U.S. dollars (US\$) at the rate of R1.00=US\$0.386 (Rs2.59=US\$1.00).

²¹Value has been converted from South African Rand (R) to U.S. dollars (US\$) at the rate of R1.00=US\$0.386 (Rs2.59=US\$1.00).

²²Value has been converted from South African Rand (R) to U.S. dollars (US\$) at the rate of R1.00=US\$0.386 (Rs2.59=US\$1.00).

²³Bartholomew, D. S. Base Metal and Industrial Mineral Deposits of Zimbabwe. Mineral Resources Series No. 22, Zimbabwe Geological Survey, Harare, Zimbabwe, 1990, pp. 33-39.

²⁴McDonald, W. R., J. L. Johnson, J. N. Greaves,

and N. Wetzel. Chromite Recovery From Northern California Ores Using a Physical Concentration Process. BuMines RI 9300, 1990, 26 pp.

²⁵Baker, D. A., and J. W. Siple. Methods for the Analysis of Mineral Chromites and Ferrochrome Slag. BuMines IC 9240, 1990, 22 pp.

²⁶Collins, W. K., and J. C. Uatson. Metallographic Etching for Carbide Volume Fraction of High-Chromium, White Cast Irons. Mater. Characterization, v. 24, 1990, pp. 379-389.

²⁷Redden, L. D., and R. Swarup. Chemical Processing of Hardface Alloy Grinding Waste. Paper in Second International Symposium—Recycling of Metals and Engineered Materials, ed. by J. H. L. van Linden, D. L. Stewart, Jr., and Y. Sahai. TMS, 1990, pp. 171-184.

²⁸Atkinson, G. B., P. D. Laverty, and D. P. Desmond. Paper in Refractory Metals: Extraction, Processing and Applications, ed. by K. C. Liddell, D. R. Sadoway, and R. G. Bautista. TMS, 1990, pp. 15-29.

²⁹Lutz, L. J., S. A. Parker, J. L. Holman, and J. B. Stephenson. Paper in Second International Symposium: Recycling of Metals and Engineered Materials, ed. by J. H. L. van Linden, D. I. Stewart, Jr., and Y. Sahai. TMS, 1990, pp. 159-169.

³⁰Technology International. Special Issue 1/91: Certified Reference Materials. Mintek, Private Bag X3015, Randburg, 2125 South Africa, 4 pp.

³¹Rath, G., T. Vljacic, H. Staubner, and J. Kunze. The Hollow Electrode—An Application To Process Chrome Ore Fines. Paper in Proceedings of the 48th Electric Furnace Conference, (New Orleans, LA, Dec. 11-14, 1990). Iron and Steel Soc. Inc., 1991, pp. 267-270.

³²Crnojevic, R., E. I. Uiewiorowski, L. R. Tinnin, and A. B. Case. Recovery of Chromium and Aluminum From FO19 Waste Materials. Paper in Second International Symposium—Recycling of Metals and Engineered Materials, ed. by J. H. L. van Linden, D. I. Stewart, Jr., and Y. Sahai. TMS, 1990, pp. 463-473.

³³Granville, A., and E. F. Statham. Profits From Processing. Nintek, Nov., 1989, pp. 10-11.

³⁴Benbow, J. Cement Kiln Refractories. Ind. Miner., No. 268, 1990, pp. 37-45.

³⁵International Chromium Development Association. Chromium Review, No. 11, Nov., 1990, 13 pp.

³⁶Skinner, P. Refractories and Ceramics. Ind. Miner., No. 276, 1990, pp. 45-51.

³⁷Griffiths, J. Minerals in Foundry Casting. Ind. Miner., No. 272, 1990, pp. 39-51.

³⁸Bebington, R. U. Chromium Metal: Consumptions & Fields of Application. Presented at Metal Bulletin 7th Minor Metals Seminar, Marbella, Spain, May 6-8 1990; available from London & Scandinavian Metallurgical Co. Ltd., 45 Wimbledon Road, London SW19 7LZ, England.

OTHER SOURCES OF INFORMATION

Bureau of Mines Publications

Chromium. Ch. in *Mineral Commodities Summaries*, annual.

Chromium. Ch. in *Minerals Yearbook*, annual.

Mineral Industry Surveys, monthly.

Other Sources

American Iron and Steel Institute.

American Metal Market.

Ceramic Bulletin.

CRU Metal Monitor.

Defense Logistics Agency, Stockpile Reports.

¹National Research Council. Recommended Dietary Allowances. Natl. Acad. of Sci., Washington, DC, 1989, pp. 241-243.

Burrows, D. Chromium: Metabolism and Toxicity. CRC Press, 1983, 184 pp.

²Stowe, C. W. (ed.). Evolution of Chromium Ore Fields. Van Nostrand Reinhold, 1987, 340 pp.

Petruscheck, W., S. Karamata, G. G. Kravchenko, Z.

The Economics of Chromium 1988
(Roskill Information Services,
London).
Engineering and Mining Journal.
Federal Register.
Ferro-Alloys Directory (Metal

Bulletin, London).
Ferro Alloys Manual (the TEX Report,
Tokyo).
Industrial Minerals (London).
Metal Bulletin (London).
Metals Price Report (London).

Metals Week.
Mining Annual Review (London).
Mining Engineering.
Mining Journal (London).
Mining Magazine.
The TEX Report (Tokyo).

BLM Library
Denver Federal Center
Rm. 50, OC-25
P.O. Box 25013
Denver, CO 80225

The following is a list of the
Bureau of Land Management
and its various offices
located throughout the United States
and its possessions.

Alaska
Arizona
California
Colorado
Connecticut
Delaware
Florida
Georgia
Hawaii
Idaho
Illinois
Indiana
Iowa
Kansas
Kentucky
Louisiana
Maine
Maryland
Massachusetts
Michigan
Minnesota
Mississippi
Missouri
Montana
Nebraska
Nevada
New Hampshire
New Jersey
New Mexico
New York
North Carolina
North Dakota
Ohio
Oklahoma
Oregon
Pennsylvania
Rhode Island
South Carolina
South Dakota
Tennessee
Texas
Utah
Vermont
Virginia
Washington
West Virginia
Wisconsin
Wyoming

Washington, D.C.
Alaska
Arizona
California
Colorado
Connecticut
Delaware
Florida
Georgia
Hawaii
Idaho
Illinois
Indiana
Iowa
Kansas
Kentucky
Louisiana
Maine
Maryland
Massachusetts
Michigan
Minnesota
Mississippi
Missouri
Montana
Nebraska
Nevada
New Hampshire
New Jersey
New Mexico
New York
North Carolina
North Dakota
Ohio
Oklahoma
Oregon
Pennsylvania
Rhode Island
South Carolina
South Dakota
Tennessee
Texas
Utah
Vermont
Virginia
Washington
West Virginia
Wisconsin
Wyoming

**BLM Library
Denver Federal Center
Bldg. 50, OC-521
P.O. Box 25047
Denver, CO 80225**

